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ADVANCED GUN FIRE CONTROL SYSTEM (AGFCS) DESIGN STUDY (PHASE II)

ATS SOFTWARE DESIGN DESCRIPTON

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The Advanced Gun Fire Control System (AGFCS) program is a multi-phase program to investigate technical approaches exhibiting potentially significant improvement in present gun fire control systems effectiveness. Phase I, the AGFCS Definition Study, considered the overall design, effectiveness, complexity and mission requirements of a post-1976 air superiority aircraft. The purpose of Phase II, the AGFCS Design Study, was to design

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Continued - Block 20 (Abstract)

an Augmented Tracking System (ATS) for possible fabrication and flight test evaluation in a later AGFCS Program Phase. The ATS includes the range and angle tracking sensors, the computer, and the software used to process the tracking signals. It provides the target-dependent variables required to solve the lead angle equation in a director AGFCS mechanization. The ATS will ultimately serve as the core of an advanced gun fire control system.

The selected configuration serves as the basic element of a modular advanced gun fire control system. Its salient feature is the use of strapdown sensors in both the angle tracking and range tracking systems. The angle sensor is the Bendix Corporation Adaptive Scan Optical Tracker (ASCOT); the range sensor is the General Electric Solid State Radar (SSR-1). Both sensors satisfy the requirements of the ATS application and have adequate technical maturity for timely fabrication and flight test. The principal ATS subsystem and software features are:

- o Principal Subsystems
  - o Bendix Adaptive Scan Optical Tracker
  - o GE Solid-State Radar
  - o ATS Digital Computer
  - o Strapdown Gyro/Accelerometer Package

- o Software Features
  - o Kalman Angle Tracking Filter
  - o Kalman Range Tracking Filter
  - o Director Gun Fire Control Equations

PREFACE

This report was prepared by the McDonnell Douglas Corporation, St. Louis Missouri, McDonnell Aircraft Company, Avionics Systems Technology Department under U.S. Air Force Contract F33615-73-C-1319. The program was administered by the Air Force Avionics Laboratory Systems Avionics Division, Wright-Patterson Air Force Base, Ohio. The Air Force project engineer directing the technical aspects of the study was Captain Richard H. Hackford Jr., AFAL/NVA.

This report summarizes the principal program activity of the Advanced Air-to-Air Gun Fire Control System Design Study, Project 7629, Task 762903, from June, 1973 to April, 1974.

The authors were R. L. Berg, who also served as Principal Investigator, Dr. W. J. Murphy, and D. E. Simmons. Contributions to this report from Messrs. J. S. Arnold, R. D. Schoeffel and G. W. Zirkle of McDonnell Aircraft Company are gratefully acknowledged. The authors also wish to acknowledge the technical guidance of Mr. E. A. Rosenkoetter, Manager, Electronics Systems Technology, McDonnell Aircraft.

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Three report VOLUMES are published under separate cover due to their volume and, in the case of VOLUME II, to protect subcontractor proprietary rights. VOLUME II is subtitled ATS Angle Sensor Design Description, VOLUME III is subtitled ATS Range Sensor Design Description, and VOLUME IV is subtitled ATS Software Design Description.

This report was submitted by the authors in April, 1974.

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1.1 INTRODUCTION

This volume describes the ATS software design. Documentation is presented in the form of computer subroutine flow charts. FORTRAN notation is used throughout and detailed descriptions of the flow charts and their contents are provided to aid assembly language programming in subsequent AGFCS program phases. Interface of the ATS computer with the individual sensors is discussed in Section 3 of the AGFCS Phase II final report.

1.2 SUMMARY

The ATS software is separated into four subroutines:

- RTRACK - contains the ATS Kalman Range Tracking Filter algorithms and the logic for ATS computer interface with the SSR-1 radar.
- ATRACK - contains the ATS Kalman Angle Tracking Filter algorithms and the logic for ATS computer interface with the ASCOT angle sensor.
- FCU - contains the filter coordinate system update algorithms as well as the generation of ASCOT pointing commands.
- DIRSGT - contains the ATS director sight algorithms used for lead angle computations.

These subroutines are documented in Sections 2, 3, 4 and 5 respectively, and are presented in their calling sequence.

A symbol definition table is presented in an appendix. This table presents in alphabetical order each FORTRAN symbol used in the ATS software, its definition, updating subroutine and value (when appropriate).

SECTION 2 SUBROUTINE RTRACK DESCRIPTION

2.1 RTRACK FLOW CHART

The RTRACK flow chart is presented as Figure 1. For convenient reference it is located at the end of this section. Subsequent subsections discuss Figure 1 in detail.

2.2 RESET MODE

A reset mode is provided to automatically reset the logic and parameters of the individual ATS subroutines at the operator's discretion. In the case of RTRACK IRESET = 1:

- o Sets the following control switches: IAUTOR = 1; IAUGR = 0
- o Sets the following counter to zero: NTRKR
- o Sets the following counter limits: MSMR = 2, MEXTR = 128
- o Initializes the average target range to zero: GPTRXA = 0
- o Initializes the driving noise covariance measurement element: SVATR; and
- o Computes constants used in the state transition matrices.

2.3 INITIAL ACQUISITION AND STEADY-STATE TRACKING MODE

To describe the operation of RTRACK during initial acquisition it is assumed that the computer has been previously reset and is now in operate (IRESET = 0). Initially the SSR-1 radar has not detected and acquired a target so that IACQR = 0. Note that IAUTOR = 1 and IAUGR = 0 from reset and, therefore, the radar is operating in its autonomous mode. In this situation, the sole function of RTRACK is to provide fixed values of range, range rate and target acceleration along the line of sight to other subroutines. These fixed values have been selected to be 2000 feet, -200 feet/second and zero respectively.

When the SSR-1 has detected and acquired a target (ILOCK = 1 and IEXTR = 0) IACQR is set to 1. This event signals the start of the initialization of RTRACK. RTRACK reaches its steady state operation after eight (8) passes (assuming IACQR remains at 1), each pass taken at 1/64 second intervals. The next few paragraphs describe important features of the first nine initial acquisition passes.

2.3.1 Initial Acquisition Pass 1

IACQR = 1 establishes the following values of control switches, counters, and counter limits:

- Control Switches:

  IAUTOR = 0 - Commands the SSR-1 to leave its Autonomous Mode.

  IAUGR = 1 - Commands the SSR-1 to enter its Augmented Mode.

  INTRKR = 1 - Indicates range tracking filter is in its initialization pass.

  IFRSTR = 1 - Indicates that this is the first update sequence after radar acquisition.

- Counters:

  NTRKR = 1 - Indicates range tracking filter is operating.

  NSMR = 0 - NSMR is the counter on the smoothing performed on measured range. During normal operation four (4) samples taken at 1/64 second intervals are smoothed (averaged) and used to update the Kalman range tracking filter every 1/16 second.

  NPREDR = 0 - NPREDR is the counter which sequences the Kalman filter update. The Kalman range tracking filter update occurs every fourth pass and only when NPREDR = 3 (5 on initialization pass only). This counter is initialized to zero so that the filter cycle is entered properly.

  NEXTR = 0 - NEXTR is the counter which accumulates extrapolation time.

- Counter Limits:

  MAVGR = 4 - MAVGR is used to indicate the number of samples used in data smoothing. It is equal to 4 except upon entering the extrapolate mode after loss of target return.

  MPREDR = 4 - MPREDR is used to time the update cycle of the Kalman range tracking filter. It is set to a value one less than the number of 1/64 second prediction intervals between each filter update. Normally MPREDR = 2 since there are three (3) prediction intervals for every filter update. However, during initialization there are five (5) prediction cycles and one Kalman filter update cycle.

Since INTRKR = 1 the range filter state variables are initialized at the measured radar range and range rate and a priori acceleration (zero). The range covariance matrix is initialized as a diagonal matrix with diagonal elements SMRPI(1) = σ_R^2; SMRPI(2) = $(16\ \sigma_R)^2$; SMRPI(3) = 32.2^2.

Since NPREDR = 0 and not greater than MPREDR = 4, the 64 Hz prediction branch is entered and NPREDR is incremented to 1. Those elements of the 1/64 second transition matrix dependent upon line-of-sight rate are computed based upon its most recent estimate. The target range and range-rate are predicted 1/64 second into the future assuming zero target acceleration. A range measurement is taken at time 1/64 second and the predicted range, GPTSFP(1), is then transmitted to the radar and loaded into its range register via the IAUGR = 1 control switch. Simultaneously the values of α and β are set to 1 and 0 respectively in the SSR-1 via the IAUGP = 1 control switch.

2.3.2 Initial Acquisition Pass 2

NTRKR is incremented to 2 and will be incremented by one each succeeding pass unless radar acquisition is lost and the radar fails to reacquire during the fixed (2 second) tracking filter extrapolation period. INTRKR is set to zero and, since the normal initial acquisition sequence is being considered here, IACQR is 1. NEXTR is set to zero since the Extrapolate mode is not being executed. NSMR = 0 and is not greater than MSMR = 2 so the most recent measurement of range is added to accumulated measurements (which were set to zero during reset). NSMR is incremented to 1.

INTRKR = 0 so NSMR is tested to determine whether or not the Kalman gains are to be computed. These gains are computed every fourth cycle and only when NSMR = 0. At this point one radar measurement has been accumulated for smoothing and NSMR = 1. NSMR will be set to zero only after four measurements have been accumulated and averaged; i.e., on Pass 5.

Since NPREDR = 1 which is not greater than MPREDR = 4, the 64 Hz branch is entered and NPREDR is incremented to 2. As before, the latest values of estimated line-of-sight rate are used to predict range and range-rate 1/64 second into the future.

IFRSTR = 1 and NSMR = 1 so the predicted values of range and range-rate are stored. It is noted that these are values predicted 2/64 second from the point of initial acquisition. Finally, IFRSTR is set to zero, a range measurement is taken and the predicted range is sent to SSR-1 to be loaded into its range register.

2.3.3 Initial Acquisition Pass 3

As in Pass 2, INTRKR is set to zero, IACQR = 1 and NEXTR is set to zero. These conditions will repeat on every pass considered hereafter until radar loss of lock is considered (IACQR = 0). Therefore, these steps will not be explicitly considered in future passes of the initial acquisition.

NTRKR is incremented to 3 and NSMR = 1 which is not greater than MSMR = 2, so the most recent radar range measurement is added to those previously accumulated. NSMR is incremented to 2.

NSMR ≠ 0 and, since NPREDR = 2 which is not greater than MPREDR = 4, NPREDR is incremented to 3. Target range and range rate are then predicted 1/64 second into the future. A range measurement is taken and the predicted range is sent to SSR-1 to be loaded into its range register.

2.3.4 Initial Acquisition Pass 4

NTRKR is incremented to 4 and NSMR = 2 which is not greater than MSMR = 2 so the most recent radar range measurement is added to those previously accumulated. NSMR is incremented to 3. It is noted that at this point three radar range measurements, each taken at 1/64 second intervals, have now been accumulated since the initial measurement. Thus, the next measurement will complete the four sample measurements used for providing a smoothed measurement at 4/64 = 1/16 second intervals.

NSMR ≠ 0 and, since NPREDR = 3 which is not greater than MPREDR = 4, NPREDR is incremented to 4. Target range and range rate are then predicted 1/64 second into the future. A range measurement is taken and the predicted range is sent to SSR-1 to be loaded into its range register.

2.3.5 Initial Acquisition Pass 5

NTRKR is incremented to 5 and NSMR = 3 which is greater than MSMR = 2 so the most recent radar range measurement is added to the three previously accumulated measurements and the total is divided by MAVGR = 4 to provide a smoothed measurement valid 2/64 of a second after initial acquisition. Radar signal-to-noise ratio is measured and the variance of the smoothed measurement is computed as a function of the signal-to-noise ratio and the number of measurements. NSMR is set to 0 and MAVGR is set to 4.

NSMR = 0 and NEXTR = 0, therefore the Kalman gains will be computed based upon the smoothed signal-to-noise ratio and the a priori covariance matrix. The range residual is then computed from the smoothed range measurements computed on this pass and the predicted range measurements computed and stored on Pass 2. It is noted that the residual computed is valid at the point in time 2/64 second after initial acquisition. The accumulated range measurements are then reset to zero.

Since NPREDR = 4 and not greater than MPREDR = 4, NPREDR is incremented to 5. Target range and range rate are then predicted 1/64 second into the future. A range measurement is taken and the predicted range is sent to SSR-1 to be loaded into its range register.

2.3.6 Initial Acquisition Pass 6

NTRKR is incremented to 6 and NSMR = 0 which is not greater than MSMR = 2 so the most recent radar range measurement is added to the accumulated measurements (which were set to zero on the previous pass). NSMR is incremented to 1.

NSMR $\neq$ 0 but NPREDR = 5 and is greater than MPREDR = 4, so that the 16 Hz Kalman Range Tracking Filter update path is entered for the first time.

First NPREDR is set to zero and MPREDR is set to 2. This initializes the 64 Hz prediction path counter and sets its limit so that the prediction path is entered three times for every one range tracking filter update path entry. Note that since this is the sixth pass the prediction path has been entered five times and 5/64 seconds have transpired since initial acquisition.

Next, the 1/16 second state transition matrix is updated based upon the most recent line-of-sight rate information.

The Kalman gains and residual computed during the fifth pass together with the predicted range state stored on the second pass are used to update the estimated range state vector. This estimated range state vector is valid for the point in time 2/64 second after initial acquisition. These estimates and measured ownship incremental velocity along the line-of-sight are then used to predict the state vector 1/16 second into the future (6/64 second after initial acquisition). Thus, the predicted range state coincides with the start of the seventh pass. After updating the predicted state vector, the estimation, SMRE, and prediction, SMRP, covariance matrices are updated. A range measurement is taken and the predicted range is sent to the SSR-1 to be loaded into its range register. The predicted range and range rate are used for the 1/64 second range prediction during the interval until the next Kalman filter update.

2.3.7 Initial Acquisition Pass 7

NTRKR is incremented to 7 and NSMR = 1 which is not greater than MSMR = 2 so the most recent radar range measurement is added to those previously accumulated. NSMR is incremented to 2.

NSMR $\neq$ 0 and, since NPREDR = 0 which is not greater than MPREDR (which was set to 2 on the previous pass), NPREDR is incremented to 1. Target range and range rate are then predicted 1/64 second into the future. A range measurement is taken and the predicted range is sent to SSR-1 to be loaded into its range register.

2.3.8 Initial Acquisition Pass 8

NTRKR is incremented to 8 and NSMR = 2 which is not greater than MSMR = 2 so the most recent radar range measurement is added to the two previously accumulated. NSMR is incremented to 3.

Since NPREDR = 1 which is not greater than NPREDR = 2, NPREDR is incremented to 2. Target range and range rate are predicted 1/64 second into the future. A range measurement is taken and the predicted range is sent to SSR-1 to be loaded into its range register.

2.3.9 Initial Acquisition Pass 9

NTRKR is incremented to 9 and NSMR = 3 which is greater than MSMR = 2 so the most recent radar range measurement is added to the three previously accumulated measurements and the total is divided by MAVGR = 4 to provide a smoothed measurement occurring 6/64 seconds after initial acquisition. Radar signal-to-noise ratio is measured and the variance of the smoothed measurement is computed as a function of the signal-to-noise ratio and the number of measurements. NSMR is reset to zero and MAVGR is set to 4.

NSMR = 0 and NEXTR = 0, therefore, the Kalman gains will be computed based on the smoothed signal-to-noise ratio and the predicted covariance matrix computed on Pass 6. The range residual is then computed from the smoothed range measurements computed on this pass and the predicted range measurements computed on Pass 6, i.e., the range tracking filter update pass. It is noted that the residual computed is valid at the point in time 6/64 second after initial acquisition. The accumulated range measurements are then reset to zero.

Since NPREDR = 2 and is not greater than MPREDR = 2, NPREDR is incremented to 3. Target range and range rate are then predicted 1/64 second into the future. A range measurement is taken and the predicted range is sent to SSR-1 to be loaded into its range register.

2.3.10 Steady-State Tracking

After the eighth pass, i.e., 8/64 second after initial acquisition, RTRACK is operating in its steady-state sequence. Pass 9 was identical to Pass 5; Pass 10 would be identical to Pass 6; Pass 11 would be identical to Pass 7 and Pass 12 would be identical to Pass 8. The next radar tracking filter update will occur on Pass 10 - 9/64 second after initial acquisition. The next measurement average will occur on Pass 13 - 12/64 second after initial acquisition.

This cycle will be repeated every 1/16 second until interrupted. Interruption can occur either by resetting the computer (IRESET = 1) or by loss of radar lock-on (IACQR = 0). The operation of the Reset mode has been previously discussed. The RTRACK Extrapolate mode used after radar break-lock is discussed in the next section.

2.4 EXTRAPOLATION MODE

The Extrapolation mode is implemented to provide a search zone command and to aid in reacquisition after loss of radar lock-on. Loss of radar lock-on is signalled by the SSR-1 setting the discrete IEXTR to one. IACQR is therefore set to zero. If two or more seconds of steady-state tracking has occurred prior to loss of lock-on, the Extrapolation mode will be entered. If less than two seconds of steady-state tracking has occurred, the SSR-1 is commanded to its Autonomous Mode (IAUTOR = 1 and IAUGR = 0).

In the following subsections the detailed operational sequence of RTRACK will be discussed on a pass by pass basis after loss of radar lock-on (assuming two or more seconds of steady-state tracking has occurred).

2.4.1 Extrapolation Mode Pass 1

NTRKR is greater than zero but IACQR = 0 so the data smoothing branch is by-passed and the extrapolation branch is entered. NEXTR is incremented to 1.

Since NEXTR is less than MEXTR = 128, the accumulated measurements are zeroed and NSMR is tested against MSMR = 2. NSMR can be any integer value from 0 to 3 and is incremented each pass in a manner identical to that used during data smoothing. This provides proper sequencing for possible subsequent reacquisition. For the same reason MAVGR is set to (4 - NSMR) so that an incomplete set of measurements can be accommodated during reacquisition. In the following paragraphs the effect of each possible NSMR value on the first pass of the extrapolate mode will be discussed.

2.4.1.1 NSMR = 0 - NSMR is incremented to 1 and MAVGR is set to 3. NSMR is not equal to zero and NPREDR = 3 which is greater than MPREDR = 2. Therefore, NPREDR is reset to zero and the Kalman range tracking filter is updated based on the last complete set of measurements taken prior to loss of radar lock-on. The tracking filter update is accomplished in the same manner as in Subsection 2.3.6. Since IAUGR = 1 and IAUTQR = 0, the SSR-1 will search in a $\pm$100 feet range gate centered about the predicted range.

2.4.1.2 NSMR = 1 - NSMR is incremented to 2 and MAVGR is set to 2. NSMR is not equal to zero and NPREDR = 0 which is not greater than MPREDR = 2 (see Subsection 2.3.7). Therefore, NPREDR is incremented to 1 and target range and range rate are predicted 1/64 second into the future and loaded into the SSR-1 range register.

2.4.1.3 NSMR = 2 - NSMR is incremented to 3 and MAVGR is set to 1. NSMR is not equal to zero and NPREDR = 1 which is not greater MPREDR = 2. (See Subsection 2.3.8). Therefore, NPREDR is incremented to 2 and target range and range rate are predicted 1/64 second into the future and loaded into the SSR-1 range register.

2.4.1.4 NSMR = 3 - NSMR is greater than MSMR = 2 so NSMR is reset to zero and MAVGR is set to 4. NSMR = 0 and NEXTR is greater than zero so the Kalman gains are zeroed. NPREDR = 2 which is not greater than MPREDR = 2 (see Subsection 2.3.9). Therefore, NPREDR is incremented to 3 and target range and range rate are predicted 1/64 second into the future and loaded into the SSR-1 range register.

2.4.2 Extrapolation Mode Pass 2

This branching of Pass 2 is dependent on the value of NSMR on the first pass. Therefore, as in the previous subsection, each possible situation will be discussed below.

2.4.2.1 NSMR = 0 - NSMR = 0 corresponds to the situation for which NSMR = 3 on the first pass of the Extrapolate mode (see Subsection 2.3.1.4). NSMR is incremented to 1. NSMR is not equal to zero and NPREDR = 3 which is greater than MPREDR = 2. Therefore, NPREDR is reset to zero and the Kalman range tracking filter is updated based on zero Kalman gains. The range state vector is extrapolated, the covariance matrices are updated and the predicted range is loaded into the SSR-1 range register.

2.4.2.2 NSMR = 1 - NSMR = 1 corresponds to the situation for which NSMR = 0 on the first pass of the Extrapolation mode (see Subsection 2.3.1.1). NSMR is incremented to 2. NSMR is not equal to zero and NPREDR = 0 which is not greater than MPREDR = 2. Therefore, NPREDR is incremented to 1 and target range and range rate are predicted 1/64 second into the future and the SSR-1 range registers loaded as before.

2.4.2.3 NSMR = 2 - NSMR = 2 corresponds to the situation for which NSMR = 1 on the first pass of the Extrapolation mode (see Subsection 2.4.1.2). NSMR is incremented to 2. NSMR is not equal to zero and NPREDR = 1 which is not greater than MPREDR = 2. Therefore, NPREDR is incremented to 2 and target range and range rate are predicted 1/64 second into the future and the SSR-1 range register is loaded as before.

2.4.2.4 NSMR = 3 - NSMR = 3 corresponds to the situation for which NSMR = 2 on the first pass of the Extrapolation mode (see Subsection 2.4.1.3). NSMR is greater than MSMR = 2 so NSMR is reset to zero and MAVGR is set to 4. NSMR is equal to zero and NEXTR not equal to zero so the Kalman gains are zeroed. NPREDR = 2 which is not greater than MPREDR = 2 so NPREDR is incremented to 3 and target range and range rate are predicted 1/64 second into the future and the SSR-1 range register is loaded as before.

2.4.3 Extrapolation Mode Passes 3 - 128

Reviewing the previous two subsections reveals that essentially three actions are performed: 1) prediction using the 1/64 second, zero acceleration algorithm; 2) zeroing the Kalman gains; and 3) updating the Kalman

filter. The pass on which these actions occur as a function of NSMR on the first pass is shown in Table 1 based on the previous discussion for the first two passes and on similar reasoning for future passes.

Note that by Pass 4 an update of the Kalman filter will have been made in all cases. This corresponds to prediction (extrapolation) by the Kalman filter algorithm. Also, it is noted that, if NSMR = 0 or the first pass, a Kalman filter update is made prior to zeroing the Kalman gains. This provides for effective utilization of radar measurements taken prior to break-lock.

If lock-on is not re-established within 128 passes (2 seconds), NEXTR will exceed MEXTR = 128. This sets the following control logic:

- o NTRKR = 0 - Indicates loss of range tracking filter.
- o NEXTR = 0 - Resets NEXTR.
- o IAUTOR = 1 - Commands autonomous SSR-1 operational mode.
  IAUGR = 0

If lock-on is re-established by the SSR-1 within 128 passes, IACQR is set to 1 when IEXTR becomes zero and RTRACK enters its Reacquisition mode. This mode is discussed in the next subsection.

TABLE 1
EXTRAPOLATION SEQUENCE SUMMARY

First Pass NSMR	Extrapolation Pass					
	1	2	3	4	5	6
0	UD	P	P	ZG&P	UD	P
1	P	P	ZG&P	UD	P	P
2	P	ZG&P	UD	P	P	ZG&P
3	ZG&P	UD	P	P	ZG&P	UD

Code P – Predicted 1/64 sec
ZG – Zero Kalman Gains.
UD – Update Kalman Filter and Predict 1/16 sec

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2.5 REACQUISITION MODE

Reacquisition capability is provided in order to take advantage of predicted range rate and target acceleration information provided during the Kalman Range Tracking Filter extrapolation cycle. RTRACK provides automatic synchronization of the extrapolation cycle with the newly available radar measurements rather than completely recycling the filter.

This speeds the reacquisition process and provides for full utilization of the Kalman filter memory. As in the case of the initial pass in the Extrapolation mode, the Reacquisition mode can be initiated with NSMR equal to any integer value from 0 to 3. Each of these cases is treated below.

When IACQR is set to 1 reacquisition is initiated. The following combinations of NSMR, MAVGR and NPREDR are possible at the beginning of Pass 1: (0, 4, 3); (1, 3, 0); (2, 2, 1); and (3, 1, 2). The Kalman filter is updated only on passes for which NPREDR = 3 and the Kalman gains are computed only on passes for which NSMR = 3 (at the beginning of the pass). These cases respectively correspond to the first and fourth initial situations enumerated above. The values of MAVGR given above correspond to the number of measurements which will be available for incorporation into the range tracking filter at the first possible synchronized update interval (non-zero Kalman gains).

In the previous subsection it was shown that the following relationship occurs between NSMR and the principal actions taken during the Extrapolation mode:

NSMR	EXTRAPOLATION MODE ACTION
0	UD
1	P
2	P
3	ZG & P

During the Reacquisiton mode NEXTR = 0 so the only difference in action is that, instead of zeroing the Kalman gains, they will be computed together with the appropriate residual.

Thus Table 2 indicates the action taken during Reacquisition passes as a function of the first pass value of NSMR. Synchronization is complete at the first Kalman tracking filter update after computation of a non-zero set of Kalman gains. Examination of Table 2 indicates that the first pass condition NSMR = 3 provides the earliest synchronization (Pass 2) while NSMR = 0 provides the latest synchronization (Pass 5). The "price" of early synchronization is that less than a full set of measurements is available at the time of update. For example, the first pass condition NSMR = 3 provides only one measurement at the first range tracking filter update; while NSMR = 0 provides a full set of four measurements. The reacquisition sequence for NSMR = 3 on the initial pass is discussed in detail in the next subsection.

2.5.1 Initial Reacquisition Pass NSMR = 3

2.5.1.1 Pass 1 - NSMR is greater than MSMR = 2 so the most recent radar measurement is added to accumulated measurements (which had been zeroed during the Extrapolation mode) and divided by MAVGR = 1. Thus, the averaged measurement corresponds to the first available measurement.

Radar signal-to-noise ratio is measured and the variance of the smoothed measurement is computed as a function of the signal-to-noise ratio and the number of measurements. NSMR is then reset to zero and MAVGR set to 4.

INTRKR = 0, NSMR = 0 and NEXTR = 0 so the Kalman gain computation branch is entered. The filter gains are then computed as a function of: 1) the measurement noise, which includes the effect of signal-to-noise ratio and the number of available measurements; and 2) the predicted state covariance matrix, which includes the effect of increasing uncertainty in the predicted state variables during extrapolation. The accumulated range measurements are then reset to zero.

Since NPREDR = 2 and is not greater than MPREDR = 2, the 1/64 second prediction branch is entered. NPREDR is incremented to 3. Range and range rate are predicted 1/64 second into the future. A range measurement is taken and the predicted range is sent to SSR-1 to be loaded into its range register.

TABLE 2
REACQUISITION SEQUENCE SUMMARY

First Pass NSMR	Reacquisition Pass					
	1	2	3	4	5	6
0	UD	P	P	CG&P	UD	P
1	P	P	CG&P	UD	P	P
2	P	CG&P	UD	P	P	CG&P
3	CG&P	UD	P	P	CG&P	UD

Code P – Predicted 1/64 sec
CG – Compute Kalman Gains
UD – Update Kalman Filter and Predict 1/16 sec

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2.5.1.2 Pass 2 - NSMR = 0 which is not greater than MSMR = 2 so the most recent radar measurement is accumulated and NSMR is incremented to 1.

NSMR is not equal to zero and NPREDR = 3 which is greater than MPREDR = 2 so the Kalman Range Tracking Filter update branch is entered. The Kalman gains are not zero, having been computed on the previous pass, so the residual is used to update the range state vector estimate. This returns RTRACK to its normal tracking cycle.

2.5.2 Initial Reacquisition Pass NSMR = 2

2.5.2.1 Pass 1 - NSMR is not greater than MSMR = 2 so the most recent radar measurement is accumulated (GPTRXA having been set to zero during the Extrapolation mode). NSMR is incremented to 3.

NSMR is not equal to zero and NPREDR = 1 which is not greater than MPREDR = 2, so NPREDR is incremented to 1. Range and range rate are predicted 1/64 second into the future. A range measurement is taken and the predicted range is sent to SSR-1 to be loaded into its range register.

2.5.2.2 Pass 2 - NSMR = 3 which is greater than MSMR = 2 so the most recent radar measurement is added to those previously accumulated and divided by MAVGR = 2 (a total of two measurements have been accumulated to this point). Radar signal-to-noise ratio is measured and the variance of the smoothed measurement is computed as a function of the signal-to-noise ratio and the number of measurements. NSMR is reset to zero and MAVGR to 4.

INTRKR = 0, NSMR = 0, and NEXTR = 0 so the Kalman gain computation branch is entered and the Kalman gains and residual are computed as previously described.

Since NPREDR = 2 which is not greater than MPREDR = 2, the 1/64 second prediction branch is entered. NPREDR is incremented to 3. Target range and range rate are predicted 1/64 second into the future. A range measurement is taken and the predicted range is sent to SSR-1 to be loaded into its range register.

2.5.2.3 Pass 3 - NSMR = 0 which is not greater than MSMR = 2 so the most recent radar measurement is added to those previously accumulated (the accumulation was zeroed on the previous pass). NSMR is incremented to 1.

NSMR is not equal to zero and MPREDR = 3 which is greater than MPREDR = 2 so the Kalman range tracking filter update branch is entered. The Kalman gains are not zero, having been computed on the previous pass, so the residual is used to update the range state vector estimate. This returns RTRACK to its normal tracking cycle.

2.5.3 Initial Reacquisition Pass NSMR = 1

This sequence is much the same as the previously discussed sequence except for the first pass. The second pass is identical to the first pass when NSMR = 2 on the initial pass. MAVGR = 3 to account for the additional range measurement.

2.5.4 Initial Reacquisition Pass NSMR = 0

This sequence is much the same as the previously discussed sequence except for the first pass. The second pass is identical to the first pass when NSMR = 1 on the initial pass. MAVGR = 4 to account for the additional range measurement.

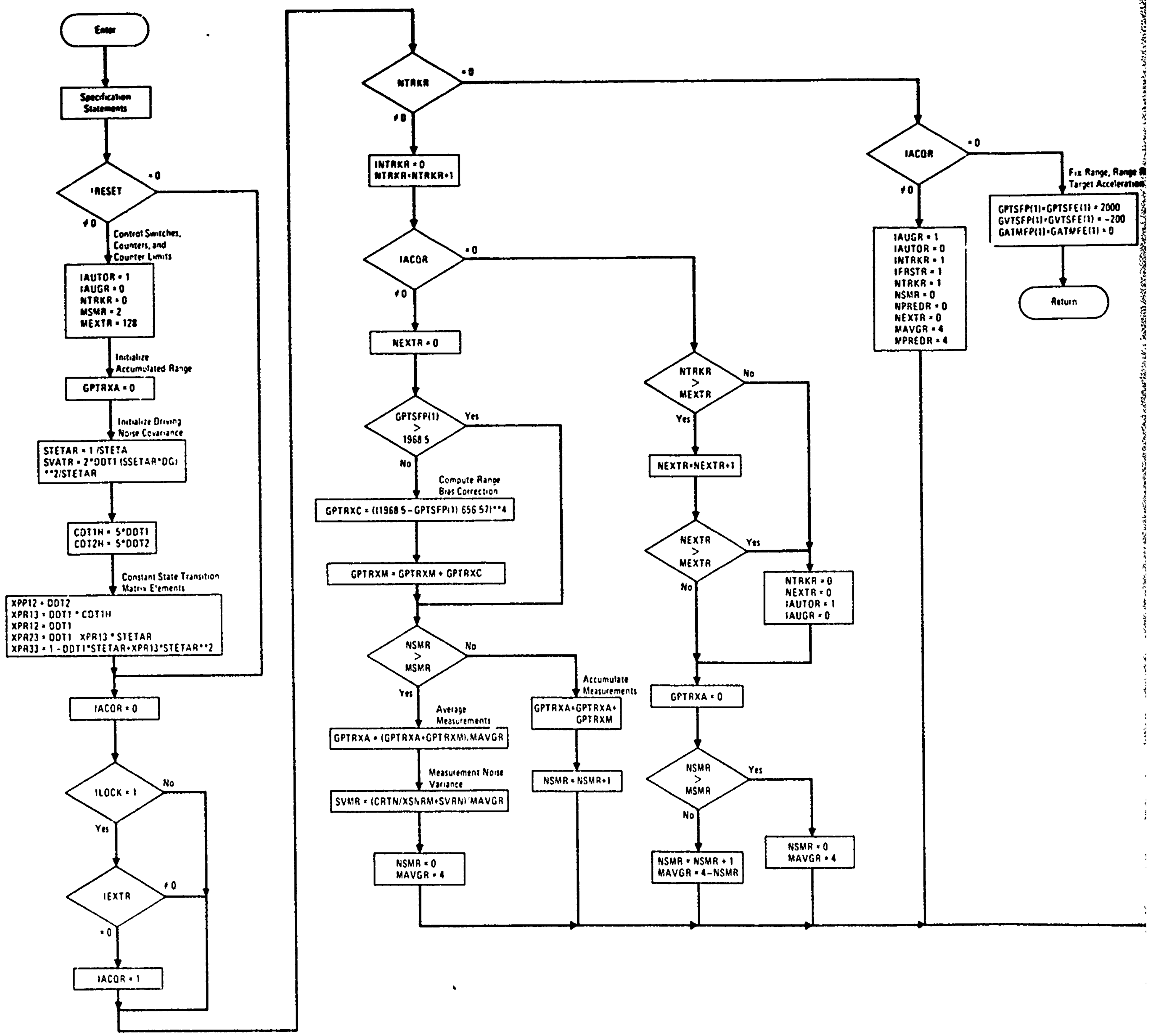
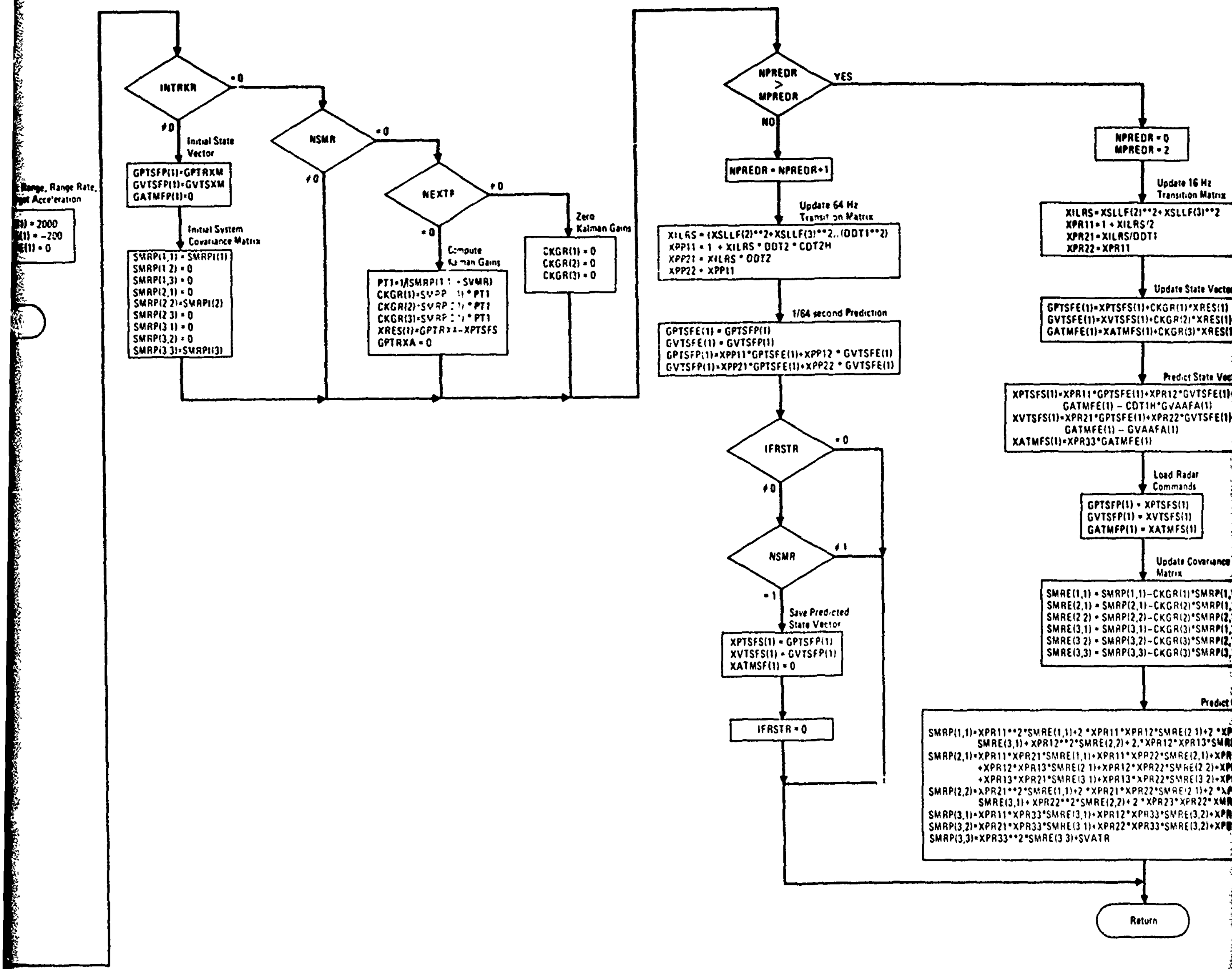


FIGURE 1
SUBROUTINE RTRACK FLOW CHART



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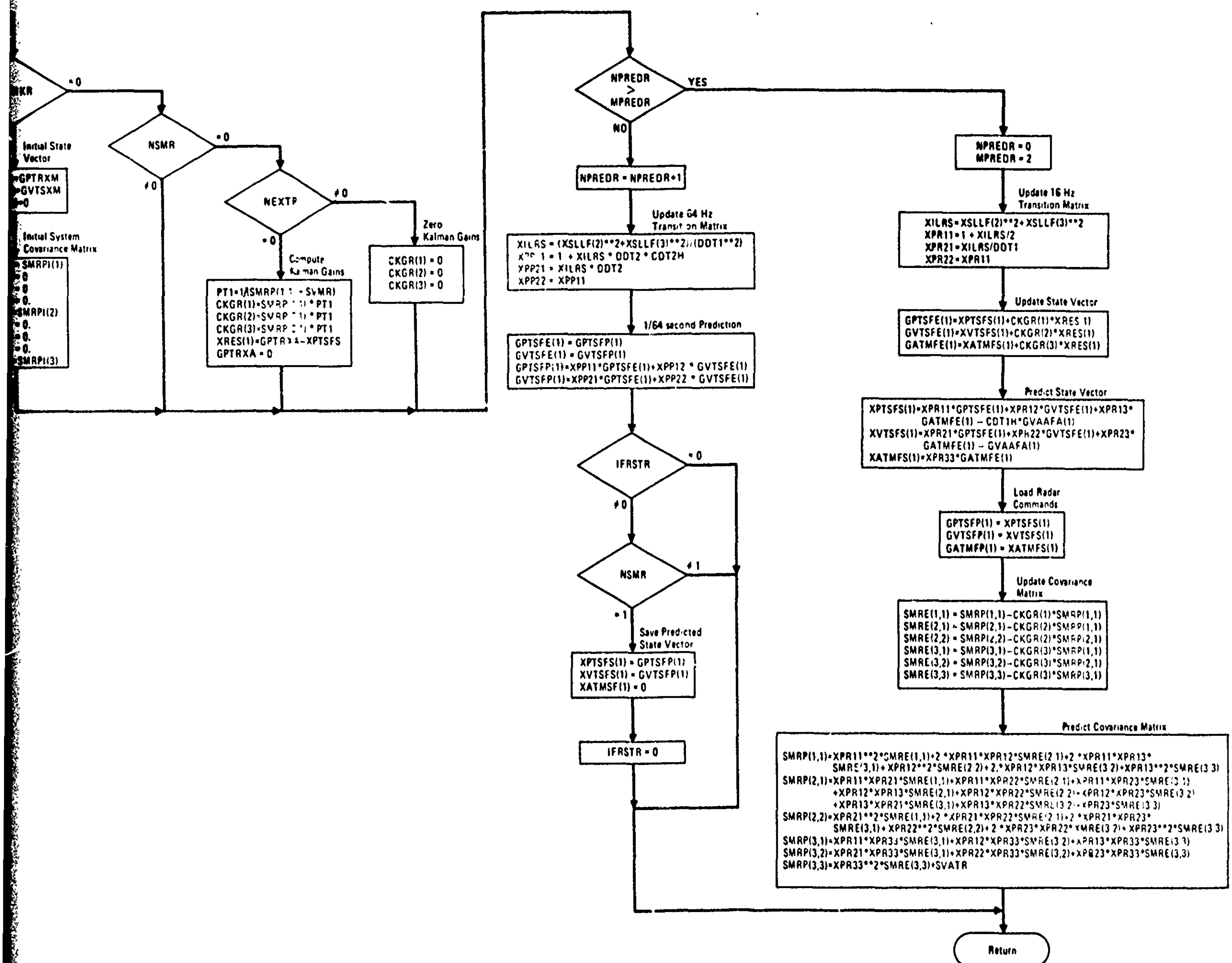
(3)



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SECTION 3 SUBROUTINE ATRACK DESCRIPTION

3.1 ATRACK FLOW CHART

The ATRACK flow chart is presented as Figure 2. For convenient reference it is located at the end of this section. Subsequent subsections discuss Figure 2 in detail.

3.2 RESET MODE

A reset mode is provided to automatically reset the logic and parameters of the individual ATS subroutines at the operator's discretion. In the case of ATRACK IRESET = 1:

- o Sets the following counter:

  NTRKA = 0 - NTRKA indicates whether ATRACK is operating in its tracking or extrapolation modes. This counter is zero until ASCOT detects a target. After ASCOT detection it counts the number of passes during which the tracking filter is in continuous tracking and extrapolation.

- o Sets the following counter limits:

  MSMA = 8 - MSMA is the limiting value of counter MSMA, which is used to sequence the smoothing of ASCOT measurements.

  MPREDA = 8 - MPREDA is the limiting value of counter NPREDA which is used to sequence the update cycle of the Kalman Angle Tracking Filter.

  MEXTA = 320 - MEXTA is the limiting value of counter NEXTA. NEXTA is the extrapolation pass counter which counts the number of passes during which the filter is in continuous extrapolation.

- o Initializes the average ASCOT error voltages and SGAP incremental velocities at zero:

  XDVFA(2) = XDVFA(3) = 0
  GVAAFA(1) = FVAAFA(2) = GVAAFA(3) = 0

- o Computes constants used in the state transition matrix and constant state transition matrix elements.

- o Initializes the driving noise covariance matrix element: SVATA

3.3 INITIAL DETECTION MODE

To describe the operation of ATRACK during initial acquisition it is assumed that the computer has been previously reset and is now in operate (IRESET = 0). Initially, ASCOT has not detected and acquired a target so that IDETA = 0 and IACQA = 0. Note that ASCOT is operating in its search mode. In this situation, the function of ATRACK is to: 1) measure ownship incremental velocities; 2) provide incremental line-of-sight (LOS) changes (body attitude changes) to the Filter Coordinate Update (FCU) subroutine; 3) provide approximate LOS rates (body rates) to the RTRACK subroutine; and, 4) compute fixed filter-to-sensor direction cosine matrix (GCSF) and quaternion (GQSF).

When ASCOT has detected a target IDETA is set to 1 by ASCOT. This event signals the start of the initialization of ATRACK. For a time after detection (up to 400 milliseconds) the ASCOT is in its initial acquisition mode. ATRACK (assuming IDETA remains 1) cycles through its initial acquisition branch at 1/160 second intervals. The next few paragraphs describe the important features of each of the initial detection passes.

3.3.1 Initial Detection - Pass 1

IDETA = 1 establishes the following values of control switches, counters and counter limits:

- Control switch

  INTRKA = 1 - Indicates the Angle Tracking Filter is in its initialization pass

- Counters

  NTRKA = 1 - Indicates that the Angle Tracking Filter is operating.

  NSMA = 5 - NSMA is the counter which sequences the smoothing of ASCOT measurements. During normal operation ten ASCOT samples taken at 1/160 second intervals are smoothed (averaged) and used to update the Kalman Angle Tracking Filter every 1/16 second. This counter is initialized at five to offset the filter by one half of the 1/16 second filter cycle interval.

  NPREDA = 0 - NPREDA is the counter which sequences the Kalman filter update. The Kalman Angle Tracking Filter update occurs every tenth pass and only when NPREDA = 9. This counter is initialized at zero so that the filter cycle is entered properly.

  NEXTA = 0 - NEXTA is the extrapolation pass counter which counts the number of passes during which the filter is in continuous extrapolation.

- **Counter Limits**

MTRKA = 65 - MTRKA is the value of NTRKA at which, if no target is acquired, the ASCOT will be returned to its search mode. A test of NTRKA against MTRKA prevents the filter from entering its extrapolation mode before acquisition.

MAVGA = 5 - MAVGA is used to indicate the number of ASCOT samples used in the smoothed ASCOT measurement. It is equal to ten except when the filter is in its extrapolation mode. MAVGA is initialized at five because, given immediate acquisition after detection, the first smoothed ASCOT measurement will contain five samples.

In addition to the initialization of the above control logic, the initial filter-to-sensor direction cosine matrix (GCSF) and filter-to-sensor quaternion (GQSF) are computed from the ASCOT deflection voltages at detection.

In this pass and in each succeeding 1/160 second pass, the measured SGAP incremental velocities and incremental body attitude changes are transformed to filter coordinates. In addition, the transformed incremental velocities are accumulated. The accumulated incremental velocities are reset to zero after the computation of the measurement residuals.

Since INTRKA = 1 the Angle Tracking Filter state variables are initialized at their a priori values. The target relative position states in filter coordinates are set to zero since the filter coordinate system was initialized pointing at the target at detection. The target relative velocity states in filter coordinates are computed from ownship incremental body attitude changes transformed to filter coordinates. The target total acceleration states in filter coordinates are initialized at ownship incremental velocities transformed to filter coordinates. The state variable covariance matrix is initialized at fixed input values.

The Kalman gains are then zeroed to force the filter to extrapolate until the target is acquired by ASCOT (IACQA = 1) and ASCOT transitions into its track mode.

Since NPREDA = 0, ASCOT reorientation commands are computed such that the a priori tracking error states, predicted 1/16 second into the future, will be nulled. These data are stored for use after the next four passes. NPREDA = 0 which is not greater than MPREDA = 8 so NPREDA is incremented to 1. This completes the first initial detection pass.

3.3.2 Initial Detection - Pass 2

NTRKA = 1 after the first pass and is incremented by one each succeeding pass, unless the ASCOT loses lock and fails to reacquire during a fixed (two second) extrapolation period. INTRKA is set to zero and remains zero, unless ASCOT loses lock and fails to reacquire during extrapolation. Since the normal initial acquisition sequence is being considered presently, IDETA = 1 and IACQA = 0. NEXTA is zero so the extrapolation mode is not being executed.

Since IACQA = 0, NTRKA = 2 which is not greater than MTRKA = 65, IDETA is not equal to zero and NSMA = 5 which is not greater than MSMA = 8, NSMA is incremented to 6 and MAVGA decremented to 4. NSMA is not equal to zero, so the Kalman gain computations are bypassed. NPREDA = 1 which is not equal to zero or greater than MPREDA = 8, so NPREDA is incremented to 2. Note that this branch is basically an "idle" branch. Its principal purpose is to maintain the proper sequencing of the logic such that in the event of ASCOT acquisition (IACQA = 1) the system will automatically transition into its steady state tracking sequence.

3.3.3 Initial Detection - Pass 3

NTRKA is incremented to 3 which is not greater than MTRKA = 65, IDETA = 1, NSMA = 6 which is not greater than MSMA = 8; hence NSMA is incremented to 7, and MAVGA is decremented to 3. NSMA is not equal to zero and NPREDA = 2 which is not zero or greater than MPREDA = 8 so that NPREDA is incremented to 3.

3.3.4 Initial Detection - Pass 4

NTRKA is incremented to 4 which is not greater than MTRKA = 65, IDETA = 1, NSMA = 7 which is not greater than MSMA = 8; hence NSMA is incremented to 8 and MAVGA is decremented to 2. NSMA is not equal to zero and NPREDA = 3 which is not zero or greater than MPREDA = 8 so NPREDA is incremented to 4.

3.3.5 Initial Detection - Pass 5

NTRKA is incremented to 5 which is not greater than MTRKA = 65, IDETA = 1, NSMA = 8 which is not greater than MSMA = 8; hence NSMA is incremented to 9 and MAVGA is decremented to 1. NSMA is not equal to zero and NPREDA = 4 which is not zero or greater than MPREDA = 8 so NPREDA is incremented to 5.

3.3.6 Initial Detection - Pass 6

NTRKA is incremented to 6 which is not greater than MTRKA = 65, IDETA = 1, NSMA = 9 which is greater than MSMA = 8; so that NSMA is reset to zero and MAVGA to 10. NSMA = 0 so the ASCOT reorientation commands computed on Pass 1 are sent to the Filter Coordinate Update subroutine. IACQA is equal to zero so the Kalman gains are zeroed. NPREDA = 5 which is not zero or greater than MPREDA = 8 so NPREDA is incremented to 6.

3.3.7 Initial Detection - Pass 7

NTRKA is incremented to 7 which is not greater than MTRKA = 65, IDETA = 1, NSMA = 0 which is not greater than MSMA = 8; so NSMA is incremented to 1 and MAVGA decremented to 9. NSMA is not equal to zero and NPREDA = 6 which is not zero or greater than MPREDA = 8 so NPREDA is incremented to 7.

3.3.8 Initial Detection - Pass 8

NTRKA is incremented to 8 which is not greater than MTRKA = 65, IDETA = 1, NSMA = 1 which is not greater than MSMA = 8; so NSMA is incremented to 2 and MAVGA is decremented to 8. NSMA is not equal to zero and NPREDA = 7 which is not zero or greater than MPREDA = 8 so NPREDA is incremented to 8.

3.3.9 Initial Detection - Pass 9

NTRKA is incremented to 9 which is not greater than MTRKA = 65, IDETA = 1, NSMA = 2 which is not greater than MSMA = 8; so NSMA is incremented to 3 and MAVGA is decremented to 7. NSMA is not equal to zero and NPREDA = 8 which is not zero or greater than MPREDA = 8 so NPREDA is incremented to 9.

Note that elapsed time to this point since detection is 9/160 seconds.

3.3.10 Initial Detection - Pass 10

NTRKA is incremented to 10 which is not greater than MTRKA = 65, IDETA = 1, NSMA = 3 which is not greater than MSMA = 8; so NSMA is incremented to 4 and MAVGA decremented to 6. NSMA is not equal to zero and NPREDA = 9 which is not zero but is greater than MPREDA = 8; so the Kalman Angle Tracking Filter branch is entered.

NPREDA is reset to zero and those elements of the state transition matrix dependent upon range and range rate are computed based on their most recent estimates. The driving noise covariance element which is dependent on the variance of the range estimate and on the filter coordinate rotation rates is computed from their most recent estimates. The state vector is updated for time zero based on zero Kalman gains and then predicted 1/16 second (time 1/16 second). Similarly the system covariance matrix is updated for time zero and predicted 1/16 second. This completes one cycle of the filter from ASCOT detection.

3.3.11 Initial Detection - Passes 11-31

Assuming no ASCOT target acquisition, IACOA remains zero, initial detection passes 11-31 will cyclicly repeat passes 1 through 10. At pass 31 of IACOA = 0 (.19 + second elapsed time from detection), the ASCOT will revert to its search mode; that is, IDETA = 0. On that pass, NEXTA and NTRKA are reset to zero and MTRKA to 31. Upon a new target detection the initial detection process will repeat as previously described.

3.3.12 Initial Detection - Pass 32

NTRKA = 0 and IDETA = 0 so that the data smoothing and sequencing logic are bypassed. The SGAP incremental velocities and incremental body attitude changes are transformed to filter coordinates. Since NTRKA = 0, the incremental change in the LOS is set equal to the measured SGAP incremental change in body attitude. The smoothed incremental velocities are set to zero. The filter-to-sensor direction cosine matrix (GCSF) and quaternion (GQSF) are

reset to their fixed search values. This branching continues as described until a new target is detected.

3.4 ACQUISITION MODE

Reviewing the initial detection sequence, it is seen that the Kalman filter update branch is entered every tenth pass, when NPREDA = 9. The remaining nine passes simply increment NPREDA by one each pass to maintain the proper sequencing. When the ASCOT has acquired the target (IACQA = 1) and the system is not extrapolating (NEXTA = 0), the system will compute a residual and a set of Kalman gains. This occurs only when NSMA = 0. Three fundamental actions, then, are performed during each 1/16 second interval when the filter is tracking: 1) update Kalman Angle Tracking Filter; 2) increment NPREDA (idle branch) and 3) compute residuals and Kalman gains. When IACQA is set to one by ASCOT, one of ten sequences of the above three actions is entered depending on the value of NSMA on the first pass after acquisition. Table 3 summarizes these sequences as a function of NSMA in the first pass after acquisition. Note that for the Kalman filter updates occurring when the initial NSMA is less than 4 the Kalman gains are zero. MAVGA given in the table refers to the number of ASCOT samples used in the computation of the smoothed measurement at the time the Kalman gains are computed. Note that by the time five passes have elapsed from the point of computing the first non-zero Kalman gains, the filter has transitioned into its normal (non-zero gain) tracking mode. A complete description of the tracking mode follows.

TABLE 3
ACQUISITION SEQUENCE SUMMARY

MAVGA**	First Pass Conditions		Pass after Acquisition									
	NSMA	NPREDA	1	2	3	4	5	6	7	8	9	10
10	0	6	I	I	I	UD*	I	I	I	I	I	CG&I
9	1	7	I	I	UD*	I	I	I	I	I	CG&I	I
8	2	8	I	UD*	I	I	I	I	I	CG&I	I	I
7	3	9	UD*	I	I	I	I	I	CG&I	I	I	I
6	4	0	I	I	I	I	I	CG&I	I	I	I	UD
5	5	1	I	I	I	I	CG&I	I	I	I	UD	
4	6	2	I	I	I	CG&I	I	I	I	UD		
3	7	3	I	I	CG&I	I	I	I	UD			
2	8	4	I	CG&I	I	I	I	UD				
1	9	5	CG&I	I	I	I	UD					

Code

I Increment NPREDA idle loop

UD Kalman filter update loop

CG Compute Kalman gains and average measurement

* Kalman gains are zero

** at the time the gains are computed

3.5 TRACKING MODE

Prior to entering the tracking mode the following control variables must be set:

IDETA = 1 - Indicates that ASCOT has detected a target.

IACQA = 1 - Indicates that ASCOT is in its tracking mode.

NTRKA > 0 - Indicates that the tracking filter has been initialized and is sequencing normally.

NSMA = 0 - Indicates that the previous accumulation of ASCOT measurements has been reset to zero.

NPREDA = 6 - Indicates that a Kalman filter update will be made in 3 passes.

NEXTA = 0 - Indicates that the filter is not in its extrapolation mode.

INTRKA = 0 - Indicates that the filter is not on an initialization pass.

3.5.1 Tracking - Pass 1

NTRKA > 0, IDETA = 1, IACQA = 1 during tracking. The ASCOT is providing pointing error voltage measurements to the filter. These measurements are transformed to filter coordinates through the most recent estimate of the sensor-to-filter coordinate transformation. NSMA = 0 which is not greater than MSMA = 8, so the most recent pointing error voltage measurements are added to accumulated measurements (which were set to zero on the previous pass). NSMA is incremented to 1. INTRKA is equal to zero so NSMA is tested to determine whether or not the Kalman gains are to be computed. These gains are computed every tenth cycle if IACQA = 1 and NSMA = 0. At this point one set of ASCOT measurements has been accumulated for smoothing and NSMA = 1.

Since NPREDA = 6 which is not zero or greater than MPREDA = 8, NPREDA is incremented to 7.

3.5.2 Tracking - Pass 2

NSMA = 1 which is not greater than MSMA = 8, so the most recent ASCOT measurements are transformed to filter coordinates and added to those previously accumulated. NSMA is incremented to 2. NSMA is not equal to zero and NPREDA = 7 which is not zero or greater than MPREDA = 8, so NPREDA is incremented to 8.

3.5.3 Tracking - Pass 3

NSMA = 2 which is not greater than NSMA = 8, so the most recent ASCOT measurements are transformed to filter coordinates and added to those previously accumulated. Note that three samples have been accumulated at this point in the sequence. NSMA is incremented to 3. NSMA is not equal to zero and NPREDA = 8 which is not zero or greater than MPREDA = 8, so NPREDA is incremented to 9.

3.5.4 Tracking - Pass 4

NSMA = 3 which is not greater than MSMA = 8 so the most recent ASCOT measurements are transformed to filter coordinates and added to those previously accumulated. NSMA is incremented to 4. NSMA is not equal to zero and NPREDA = 9 which is not zero but is greater than MPREDA = 8, so the 16 Hz Kalman Angle Tracking Filter branch is entered.

NPREDA is reset to zero and the 1/16 second state transition matrix is updated based on the most recent estimates of range and range rate. The state vector estimates (for time 9/160 seconds in the past) are then updated based on the Kalman gains and residual measurements computed at the end of the previous cracking sequence. (The gains will be zero if this is the first pass through this sequence.) These estimates and measured ownship incremental velocities in filter coordinates are used to predict the state vector to time 1/160 seconds into the future. (The prediction was over an internal of 1/16 second - 9/160 to + 1/160 seconds.) Similarly the system covariance matrix is then updated and predicted.

3.5.5 Tracking - Pass 5

NSMA = 4 which is not greater than MSMA = 8 so the most recent ASCOT measurements are transformed to filter coordinates and added to those previously accumulated. NSMA is incremented to 5. NSMA is not equal to zero and NPREDA = 0 so the ASCOT reorientation command computations are executed. NPREDA = 0 which is not greater than MPREDA = 8 so NPREDA is incremented to 1.

3.5.6 Tracking - Pass 6

NSMA = 5 which is not greater than MSMA = 8, so the most recent ASCOT measurements are transformed to filter coordinates and added to those previously accumulated. MSMA is incremented to 6. NSMA is not equal to zero and NPREDA = 1 which is not zero or greater than MPREDA = 8 so NPREDA is incremented to 2.

3.5.7 Tracking - Pass 7

NSMA = 6 which is not greater than MSMA = 8, so the most recent ASCOT measurements are transformed to filter coordinates and added to those previously accumulated. NSMA is incremented to 7. NSMA is not equal to zero and NPREDA = 2 which is not zero or greater than MPREDA = 8 so NPREDA is incremented to 3.

3.5.8 Tracking - Pass 8

NSMA = 7 which is not greater than MSMA = 8, so the most recent ASCOT measurements are transformed to filter coordinates and added to those previously accumulated. NSMA is incremented to 8. NSMA is not equal to zero and NPREDA = 3 which is not zero or greater than MPREDA = 8 so NPREDA is incremented to 4.

3.5.9 Tracking - Pass 9

NSMA = 8 which is not greater than MSMA = 8, so the most recent ASCOT measurements are transformed to filter coordinates and added to those previously accumulated. NSMA is incremented to 9. NSMA is not equal to zero and NPREDA = 4 which is not zero or greater than MPREDA = 8 so NPREDA is incremented to 5.

3.5.10 Tracking - Pass 10

NSMA = 9 which is greater than MSMA = 8, so the most recent ASCOT measurements are added to those previously accumulated and the total accumulated measurement is divided by MAVGA = 10. Thus, the average of the measurements over the previous ten passes has been computed. NSMA is then reset to zero and MAVGA to 10 (MAVGA could differ from 10 depending upon initial entry conditions).

NSMA is zero so the stored ASCOT reorientation commands are sent to the Filter Coordinate Update Subroutine. IACQA = 1 and NEXTA = 0 so the Kalman gain branch is entered. The Kalman gains and the residuals are computed after which the averaged measurements are reset to zero to initialize the succeeding accumulation. MTRKA is set equal to NTRKA to prepare the filter for possible subsequent extrapolation. NPREDA = 5 which is not greater than MPREDA = 8 so that NPREDA is incremental to 6.

3.5.11 Steady State Tracking Sequence

From the previous pass, NSMA = 0 and NPREDA = 6 which duplicates the conditions at the beginning of tracking Pass 1. Therefore, Pass 11 is identical to Pass 1; Pass 12 is identical to Pass 2; Pass 13 is identical to Pass 3; etc. This cycle will be repeated every 1/16 second until interrupted. Interruption can occur either by manually resetting the computer (IRESET = 1) or by loss of ASCOT lock (IACQA = 0 and IDETA = 0). The operation of the reset mode has been previously discussed. The ATRACK extrapolation mode used after ASCOT break-lock is discussed in the next section.

3.6 EXTRAPOLATION MODE

The Extrapolation mode is implemented to: 1) provide a deflection voltage to position the ASCOT search field-of-view and 2) aid in Kalman Angle Tracking Filter reacquisition when the ASCOT can not maintain tracking. Loss of ASCOT lock-on is signaled by the ASCOT setting IDETA and IACQA to zero.

When NTRKA is greater than zero but IACQA = 0, the data smoothing branch is bypassed and the extrapolation branch is entered if NTRKA is greater than MTRKA (see 3.3.1 and 3.5.10). NEXTA is incremented to 1.

Since NEXTA is less than MEXTA = 320 the accumulated measurements are zeroed and NSMA is tested against MSMA = 8. NSMA can be any integer value from 0 to 9 and is incremented each pass in a manner similar to the initial detection sequence. This provides proper sequencing for possible subsequent reacquisition. For the same reason, MAVGA is set to (10 - NSMA) so that an incomplete set of measurements can be accommodated during reacquisition. The following paragraphs discuss the effects of each possible NSMA value on the first pass of the extrapolation mode.

Table 4 shows the extrapolation sequence as a function of the initial pass condition of NSMA. Note that when the initial NSMA is less than 4 a Kalman filter update is made prior to zeroing the Kalman gains. This provides for effective utilization of ASCOT measurements taken prior to break-lock.

TABLE 4
EXTRAPOLATION SEQUENCE SUMMARY

First Pass Conditions		Extrapolation Pass									
NSMA	NPREDA	1	2	3	4	5	6	7	8	9	10
0	6	I	I	I	UD*	I	I	I	I	I	ZG&I
1	7	I	I	UD*	I	I	I	I	I	ZG&I	I
2	8	I	UD*	I	I	I	I	I	ZG&I	I	I
3	9	UD*	I	I	I	I	I	ZG&I	I	I	I
4	0	I	I	I	I	I	ZG&I	I	I	I	UD**
5	1	I	I	I	I	ZG&I	I	I	I	UD**	I
6	2	I	I	I	ZG&I	I	I	I	UD**	I	I
7	3	I	I	ZG&I	I	I	I	UD**	I	I	I
8	4	I	ZG&I	I	I	I	UD**	I	I	I	I
9	5	ZG&I	I	I	I	UD**	I	I	I	I	I

Code
I -- Increment NPREDA idle loop
UD -- Kalman filter update loop
ZG -- Zero Kalman gains
* -- Update made with gains and measurement previously computed
** -- Kalman gains are zero

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If lock-on is not re-established in 320 passes (2 seconds), NEXTA will exceed MEXTA = 320. This sets the following control logic:

- o NTRKA = 0 - Indicates loss of angle tracking filter. ASCOT automatically reverts to its search mode.

- o NEXTA = 0 - Resets NEXTA

- o MTRKA = 65 - Resets the initial acquisition counter limit.

If target acquisition reoccurs within 320 passes, IACQA is set to 1 and ATRACK enters its reacquisition mode. The differences between acquisition and reacquisition are: 1) the filter states and covariance are not re-initialized; and 2) the pointing error in volts must be computed as the difference between the target location at detection and the search field pointing command. The filter takes advantage of the information provided during the Kalman Angle Tracking Filter extrapolation cycle. ATRACK provides automatic synchronization of the extrapolation cycle with newly available ASCOT measurements, as previously described in the initial acquisition sequence, rather than completely recycling the filter. This speeds the re-acquisition process and provides for full utilization of the Kalman filter memory.

When ASCOT detects a target while ATRACK is in its extrapolation mode (< 321 passes) the reacquisition sequence is initiated. Extrapolation continues after detection as previously described, except that the 320 pass extrapolation limit is bypassed. This is done to allow the ASCOT to acquire when detection occurs after 1.81 seconds of extrapolation. For a time (up to 190 milliseconds) after the new detection ATRACK is in its initial re-acquisition mode. During this time the control logic is sequenced to prepare ATRACK for subsequent reacquisition.

When IACQA is set to one, ATRACK enters a sequence similar to the acquisition mode (see Subsection 3.4). The difference being the fact that the ASCOT measurement is computed as described above. After MAVGA computed measurements have been accumulated and averaged, NEXTA is reset to zero and ASCOT pointing error voltage measurements are again processed as in normal tracking.

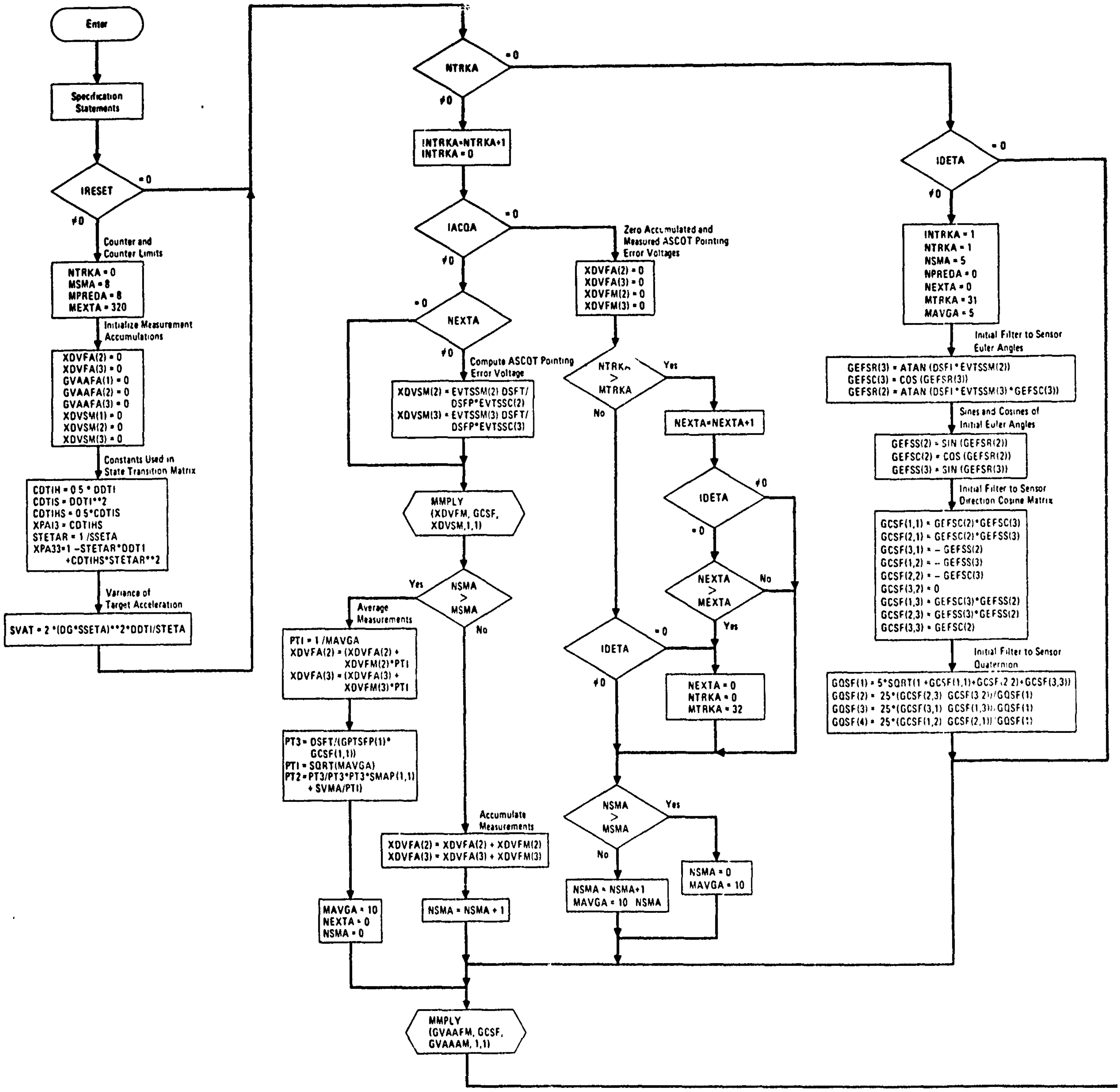

FIGURE 2
SUBROUTINE ATRACK FLOW CHART

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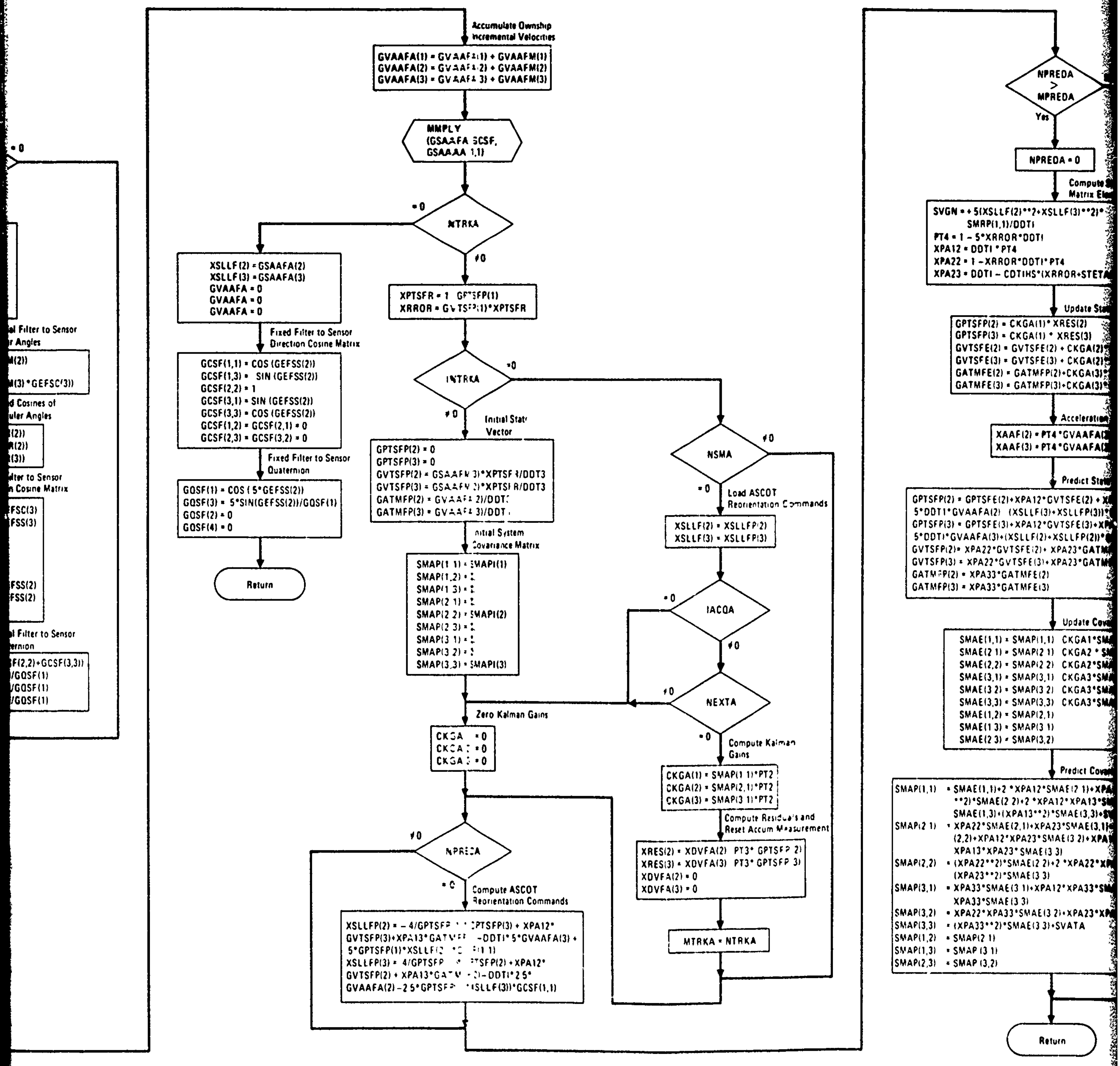
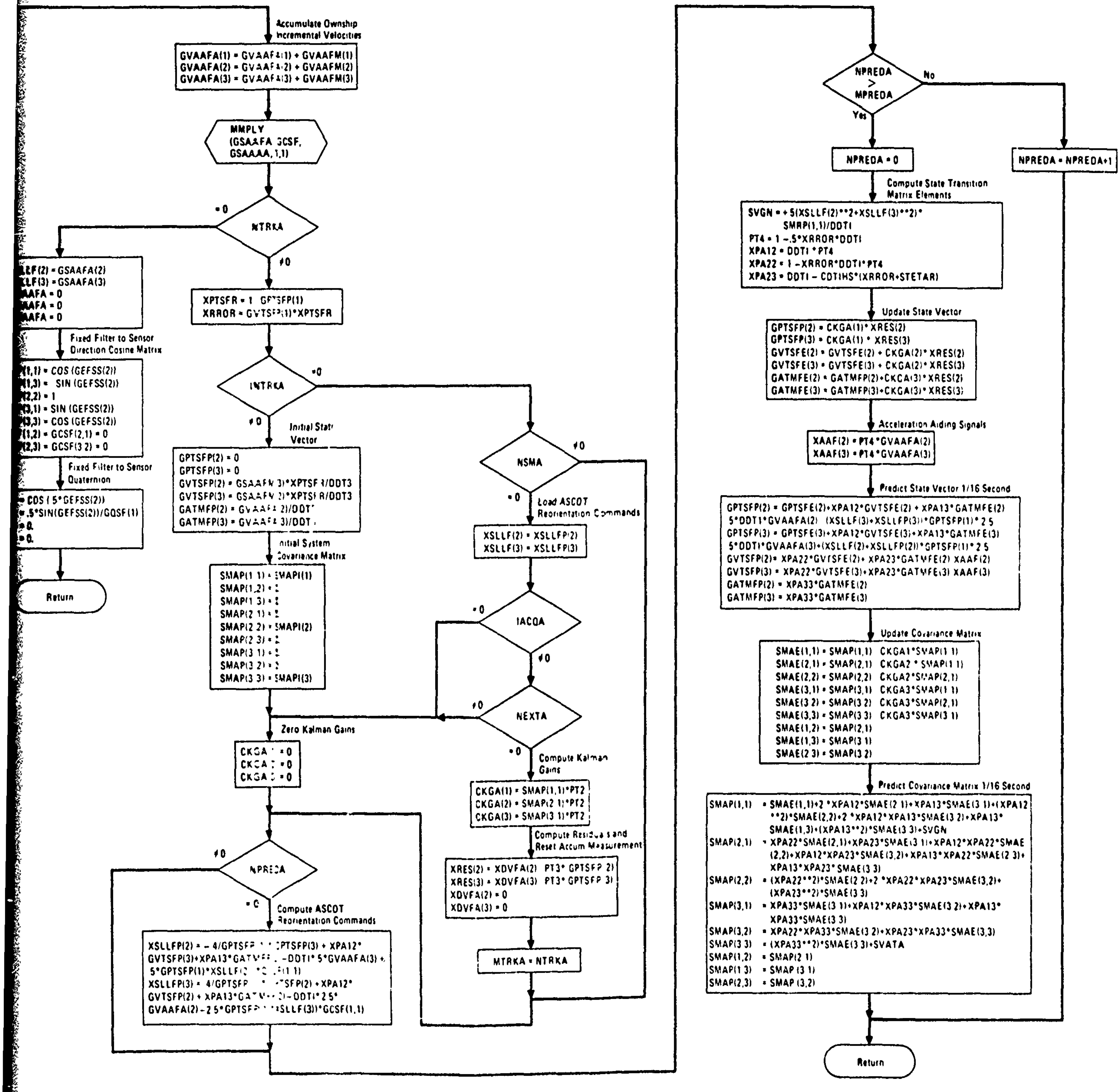


Accumulate Ownship Incremental Velocities
MMPLY
NTRKA
XPTSFR = 1
Fixed Filter to Sensor Direction Cosine Matrix
GCSF(1,2) = GCSF(2,1) = 0
GCSF(2,3) = GCSF(3,2) = 0
Fixed Filter to Sensor Quaternion
GQSF(2) = 0
GQSF(4) = 0
Return
INTRKA
Initial State Vector
GPTSFP(2) = 0
GPTSFP(3) = 0
NSMA
Load ASCOT Reorientation Commands
IACQA
NEXTA
Compute Kalman Gains
Compute Residuals and Reset Accum Measurement
XDVFA(2) = 0
XDVFA(3) = 0
MTRKA = NTRKA
Zero Kalman Gains
NPREDA
Compute ASCOT Reorientation Commands
NPREDA > MPREDA
Yes
NPREDA = 0
PT4 = 1 – 5*XRROR*DDTI
XPA12 = DDTI * PT4
Return



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SECTION 4 SUBROUTINE FCU DESCRIPTION

4.1 FCU FLOW CHART

The FCU subroutine flow chart is presented as Figure 3.

4.2 RESET MODE

A reset mode is provided to automatically reset the logic and parameters of the individual ATS subroutines at the operator's discretion. In the case of FCU, IRESET = 1 initializes the saved ownship earth-to-body quaternion when in platform mode (IPLAT = 1).

4.3 ASCOT COMMAND MODE

Subroutine Filter Coordinate Update (FCU) has three functions: 1) computes ownship body attitude changes in its platform mode, 2) updates the filter-to-sensor quaternion (GQSF) and direction cosine matrix (GCSF), and 3) computes ASCOT pointing voltages.

4.3.1 ATS Strapdown Mode

This mode is executed when the ATS system employs an SGAP for the measurement of ownship body attitude changes. This mode is entered when IPLAT = 0. Before ASCOT acquires a target (IACQA = 0) NTRKA is equal to zero. Therefore the predicted filter-to-sensor direction cosine elements required to compute ASCOT pointing voltages are set to the fixed values computed in subroutine ATRACK. ASCOT pointing voltages are then computed.

When ASCOT acquires a target (IACQA = 1) NTRKA will no longer equal zero and the filter-to-sensor quaternion update branch is entered. The incremental change of the sensor coordinate system with respect to the filter coordinate system is computed from incremental changes of the filter coordinate system computed in subroutine ATRACK and incremental body attitude changes measured by the SGAP. The filter-to-sensor quaternion is then updated for next 1/160 second interval and the filter-to-sensor direction cosine matrix is computed. The quaternion is then predicted 1/160 second into the future and ASCOT pointing voltages are computed for the next measurement interval. This cycle is repeated every 1/160 second until interrupted either manually or by loss of ASCOT acquisition after which the system will recycle as previously described.

4.3.2 ATS Platform Mode

This mode is executed when the ATS system employs an inertial platform rather than a SGAP. This mode is entered when IPLAT = 1. The sines and cosines of ownship earth-to-body Euler angles are measured in the inertial system and the earth-to-body direction cosine matrix is computed. Ownship incremental body attitude changes are then computed. The remainder of this mode is identical to the strapdown mode previously described.

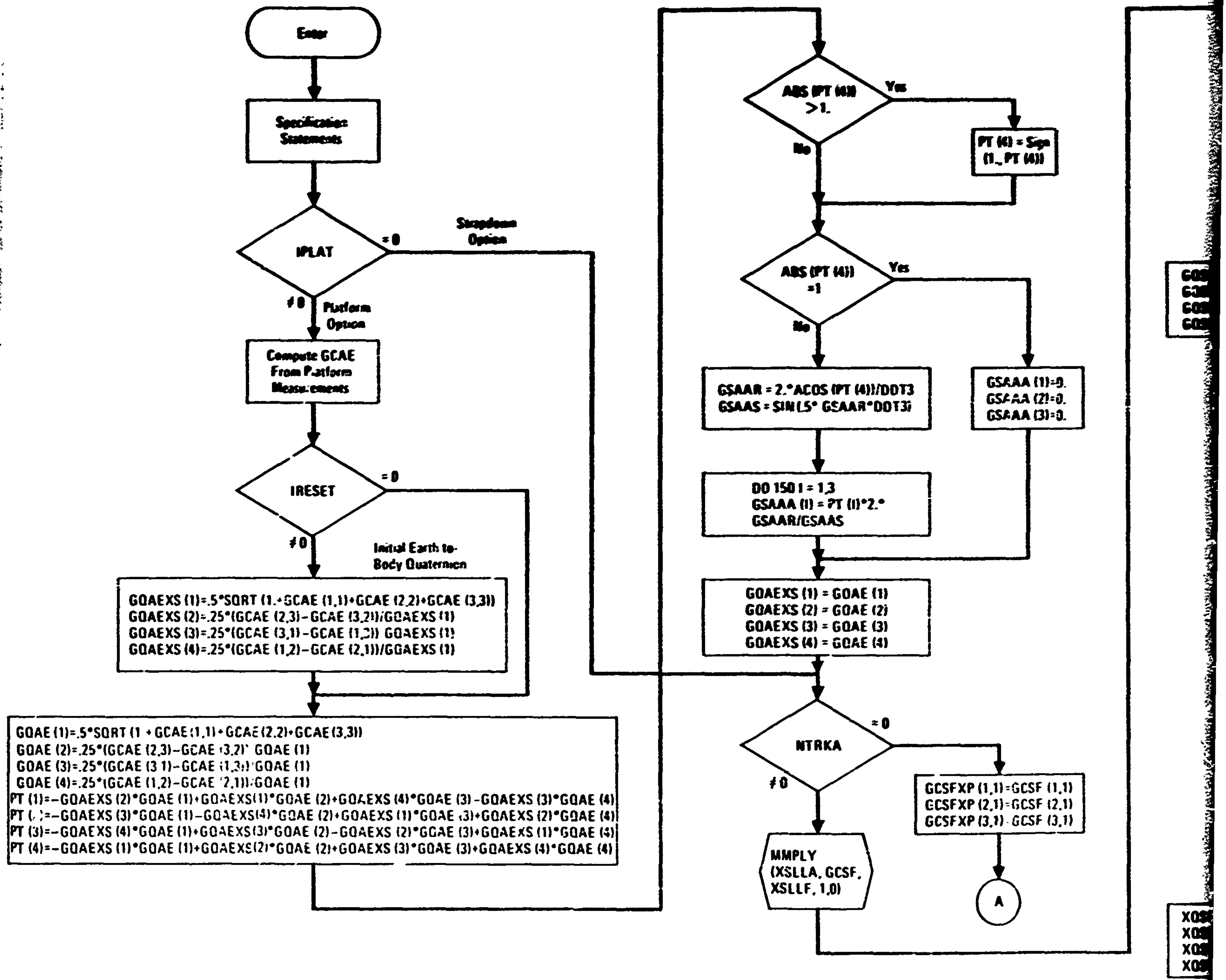


FIGURE 3
SUBROUTINE FCU FLOW CHART

GP74 0122 137

```
XSLAA (1)=GSAAA (1)
XSLAA (2)=GSAAA (2)-XSLLA (2)
XSLAA (3)=GSAAA (3)-XSLLA (3)
```

```
XILR=.25*(XSLAA(1)**2+XSLAA(2)**2+XSLAA(3)**2)
XILC=1.-.5*(XILR)
```

Update Filter-to-Sensor Quaternion

```
GOSFXP (1)=XILC*GOSF (1)-.5*(XSLAA (1)*GOSF (2)+XSLAA (2)*GOSF (3)+XSLAA (3) *GOSF (4))
GOSFXP (2)=XILC*GOSF (2)+.5 (XSLAA (1)*GOSF (1)-XSLAA (2)*GOSF (4)+XSLAA (3) *GOSF (3))
GOSFXP (3)=XILC*GOSF (3)+.5 (XSLAA (1)*GOSF (4)+XSLAA (2)*GOSF (1)-XSLAA (3) *GOSF (2))
GOSFXP (4)=XILC*GOSF (4)-.5 (XSLAA (1)*GOSF (3)-XSLAA (2)*GOSF (2)-XSLAA (3)*GOSF (1))
```

```
XQNF=1./SQRT(GOSFXP (1)**2+GOSFXP (2)**2+GOSFXP (3)**2+GOSFXP (4)**2)
```

```
GOSF (1)=GOSFXP (1)*XQNF
GOSF (2)=GOSFXP (2)*XQNF
GOSF (3)=GOSFXP (3)*XQNF
GOSF (4)=GOSFXP (4)*XQNF
```

```
XQSFS (1)=GOSF (1)**2
XQSFS (2)=GOSF (2)**2
XQSFS (3)=GOSF (3)**2
XQSFS (4)=GOSF (4)**2
```

Filter-to-Sensor Direction Cosine Matrix

```
GCSF (1,1)=XQSFS (1)+XQSFS (2)-XQSFS (3)- XQSFS (4)
GCSF (1,2)=2.*(GOSF (1)*GOSF (4)+GOSF (2)*GOSF (3))
GCSF (1,3)=2.*(GOSF (2)*GOSF (4)-GOSF (1)*GOSF (3))
GCSF (2,1)=2.*(GOSF (2)*GOSF (3)-GOSF (1)*GOSF (4))
GCSF (2,2)=XQSFS(1)-XQSFS(2)+XQSFS(3)-XQSFS(4)
GCSF (2,3)=2.*(GOSF (1)*GOSF (2)+GOSF (3)*GOSF (4))
GCSF (3,1)=2.*(GOSF (1)*GOSF (3)+GOSF (2)*GOSF (4))
GCSF (3,2)=2.*(GOSF (3)*GOSF (4)-GOSF (1)*GOSF (2))
GCSF (3,3)=XQSFS (1)-XQSFS (2)-XQSFS (3)+XQSFS (4)
```

Predict Filter-to-Sensor Quaternion

```
XQSFXP (1)=XILC*GOSF (1)-.5*(XSLAA (1)*GOSF (2)+XSLAA (2)*GOSF (3)+XSLAA (3) *GOSF (4))
XQSFXP (2)=XILC*GOSF (2)+.5*(XSLAA (1)*GOSF (1)-XSLAA (2)*GOSF (4)+XSLAA (3) *GOSF (3))
XQSFXP (3)=XILC*GOSF (3)+.5*(XSLAA (1)*GOSF (4)+XSLAA (2)*GOSF (1)-XSLAA (3) *GOSF (2))
XQSFXP (4)=XILC*GOSF (4)-.5*(XSLAA (1)*GOSF (3)-XSLAA (2)*GOSF (2)-XSLAA (3) *GOSF (1))
```

```
XQNF=1./SQRT(XQSFXP (1)**2+XQSFXP (2)**2+XQSFXP (3)**2+XQSFX
```

```
GQSFXP (1)=XQSFXP (1)*XQNF
GQSFXP (2)=XQSFXP (2)*XQNF
GQSFXP (3)=XQSFXP (3)*XQNF
GQSFXP (4)=XQSFXP (4)*XQNF
```

```
XQSFS (1)=GQSFXP (1)**2
XQSFS (2)=GQSFXP (2)**2
XQSFS (3)=GQSFXP (3)**2
XQSFS (4)=GQSFXP (4)**2
```

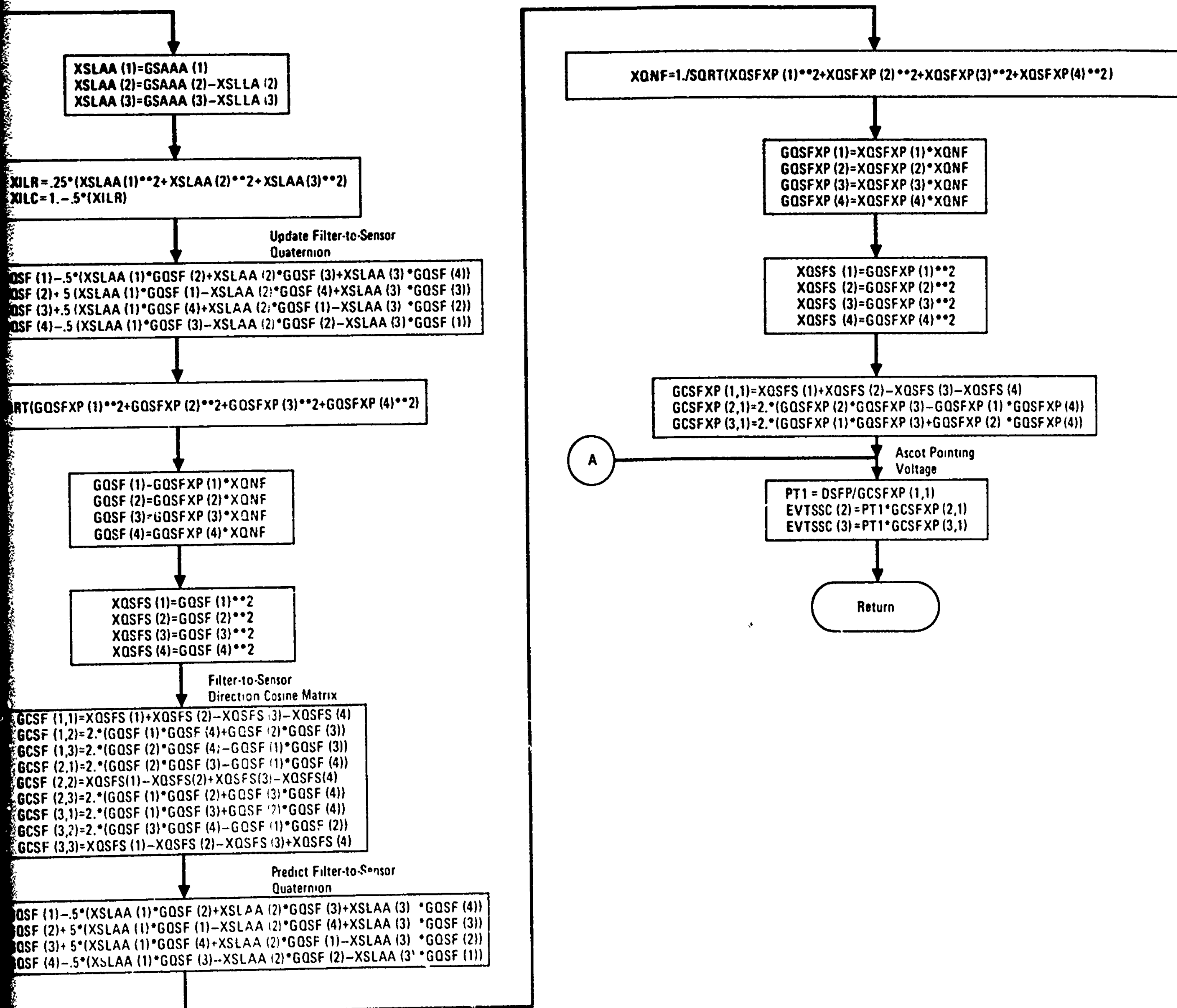
```
GCSFXP (1,1)=XQSFS (1)+XQSFS (2)-XQSFS (3)-XQSFS (4)
GCSFXP (2,1)=2.*(GQSFXP (2)*GQSFXP (3)-GQSFXP (1) *GQSFX
GCSFXP (3,1)=2.*(GQSFXP (1)*GQSFXP (3)+GQSFXP (2) *GQSFX
```

A

Ascot Pointing Voltage

```
PT1 = DSFP/GCSFXP (1,1)
EVTSSC (2) = PT1*GCSFXP (2,1)
EVTSSC (3) = PT1*GCSFXP (3,1)
```

Return



XSLAA (1)=GSAAA (1)
XSLAA (2)=GSAAA (2)−XSLLA (2)
XSLAA (3)=GSAAA (3)−XSLLA (3)
XILR=.25*(XSLAA(1)**2+XSLAA(2)**2+XSLAA(3)**2)
XILC=1.−.5*(XILR)
Update Filter-to-Sensor Quaternion
QSF (1)−.5*(XSLAA (1)*GQSF (2)+XSLAA (2)*GQSF (3)+XSLAA (3)*GQSF (4))
QSF (2)+.5 (XSLAA (1)*GQSF (1)−XSLAA (2)*GQSF (4)+XSLAA (3) *GQSF (3))
QSF (3)+.5 (XSLAA (1)*GQSF (4)+XSLAA (2)*GQSF (1)−XSLAA (3) *GQSF (2))
QSF (4)−.5 (XSLAA (1)*GQSF (3)−XSLAA (2)*GQSF (2)−XSLAA (3)*GQSF (1))
RT(GQSFXP (1)**2+GQSFXP (2)**2+GQSFXP (3)**2+GQSFXP (4)**2)
GQSF (1)=GQSFXP (1)*XQNF
GQSF (2)=GQSFXP (2)*XQNF
GQSF (3)=GQSFXP (3)*XQNF
GQSF (4)=GQSFXP (4)*XQNF
XQSFS (1)=GQSF (1)**2
XQSFS (2)=GQSF (2)**2
XQSFS (3)=GQSF (3)**2
XQSFS (4)=GQSF (4)**2
Filter-to-Sensor Direction Cosine Matrix
GCSF (1,1)=XQSFS (1)+XQSFS (2)−XQSFS (3)−XQSFS (4)
GCSF (1,2)=2.*(GQSF (1)*GQSF (4)+GQSF (2)*GQSF (3))
GCSF (1,3)=2.*(GQSF (2)*GQSF (4)−GQSF (1)*GQSF (3))
GCSF (2,1)=2.*(GQSF (2)*GQSF (3)−GQSF (1)*GQSF (4))
GCSF (2,2)=XQSFS(1)−XQSFS(2)+XQSFS(3)−XQSFS(4)
GCSF (2,3)=2.*(GQSF (1)*GQSF (2)+GQSF (3)*GQSF (4))
GCSF (3,1)=2.*(GQSF (1)*GQSF (3)+GQSF (2)*GQSF (4))
GCSF (3,2)=2.*(GQSF (3)*GQSF (4)−GQSF (1)*GQSF (2))
GCSF (3,3)=XQSFS (1)−XQSFS (2)−XQSFS (3)+XQSFS (4)
Predict Filter-to-Sensor Quaternion
QSF (1)−.5*(XSLAA (1)*GQSF (2)+XSLAA (2)*GQSF (3)+XSLAA (3) *GQSF (4))
QSF (2)+.5*(XSLAA (1)*GQSF (1)−XSLAA (2)*GQSF (4)+XSLAA (3) *GQSF (3))
QSF (3)+.5*(XSLAA (1)*GQSF (4)+XSLAA (2)*GQSF (1)−XSLAA (3) *GQSF (2))
QSF (4)−.5*(XSLAA (1)*GQSF (3)−XSLAA (2)*GQSF (2)−XSLAA (3) *GQSF (1))
XQNF=1./SQRT(XQSFXP (1)**2+XQSFXP (2)**2+XQSFXP(3)**2+XQSFXP(4)**2)
GQSFXP (1)=XQSFXP (1)*XQNF
GQSFXP (2)=XQSFXP (2)*XQNF
GQSFXP (3)=XQSFXP (3)*XQNF
GQSFXP (4)=XQSFXP (4)*XQNF
XQSFS (1)=GQSFXP (1)**2
XQSFS (2)=GQSFXP (2)**2
XQSFS (3)=GQSFXP (3)**2
XQSFS (4)=GQSFXP (4)**2
GCSFXP (1,1)=XQSFS (1)+XQSFS (2)−XQSFS (3)−XQSFS (4)
GCSFXP (2,1)=2.*(GQSFXP (2)*GQSFXP (3)−GQSFXP (1) *GQSFXP (4))
GCSFXP (3,1)=2.*(GQSFXP (1)*GQSFXP (3)+GQSFXP (2) *GQSFXP (4))
A
Ascot Pointing Voltage
PT1 = DSFP/GCSFXP (1,1)
EVTSSC (2)=PT1*GCSFXP (2,1)
EVTSSC (3)=PT1*GCSFXP (3,1)
Return

SECTION 5 SUBROUTINE DIRSGT DESCRIPTION

5.1 DIRSGT FLOW CHART

The DIRSGT subroutine flow chart is presented in Figure 4.

5.2 RESET MODE

A reset mode is provided to automatically reset the logic and parameters of the individual ATS subroutines at the operator's discretion. In the case of DIRSGT muzzle velocity is transformed to body coordinates and stored.

5.3 OPERATIONAL MODE

Director sight computations are dependent upon the availability of angle tracking data. Until IACQA = 1, that is until the ASCOT acquires a target, the sight computations are by-passed.

When IACQA is set to 1 by ASCOT the director sight computations are entered. There are four basic sight computations: 1) the bullet time-of-flight computation; 2) the future bullet computation; 3) the future target position computation; and 4) the lead angle computation.

Bullet time-of-flight is computed from the most recent estimates of range and range rate computed in RTRACK. Measured ownship velocity and altitude is assumed available from an Air Data Computer (during ATS flight test these inputs may be input data). Future bullet position is predicted one time-of-flight using measured ownship velocity and body rates and the stored muzzle velocity. Target position is then predicted one time-of-flight using the most recent estimates of target position, velocity and acceleration computed in ATRACK. Predicted bullet miss distance is computed as the difference between predicted bullet position and predicted target position and is transformed to gunline coordinates. The required lead angle is then computed.

This cycle continues until interrupted. Interruption can occur either by manually resetting the computer (IRESET = 1) or by loss of angle tracking.

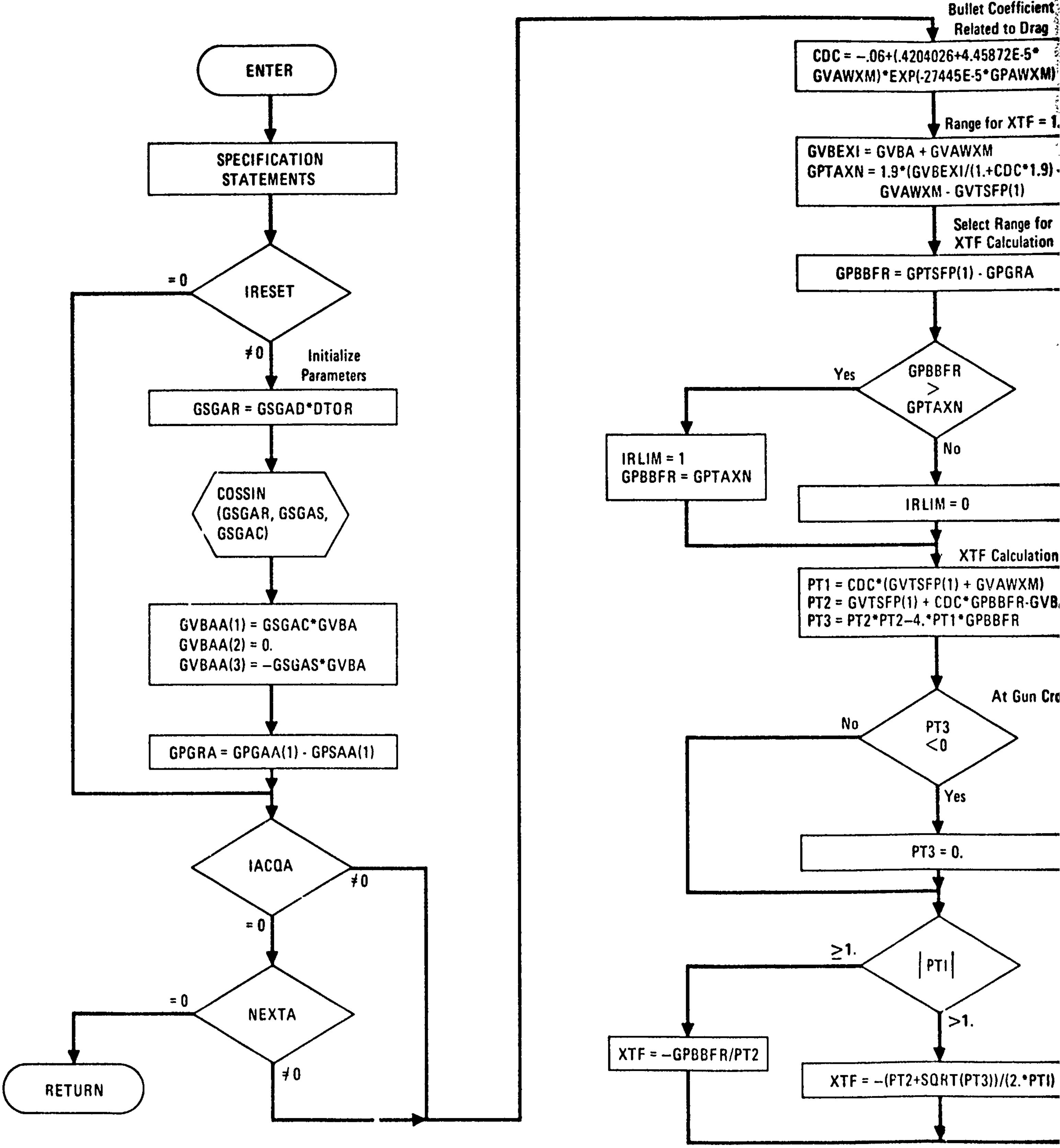


FIGURE 4
SUBROUTINE DIRSGT FLOW CHART

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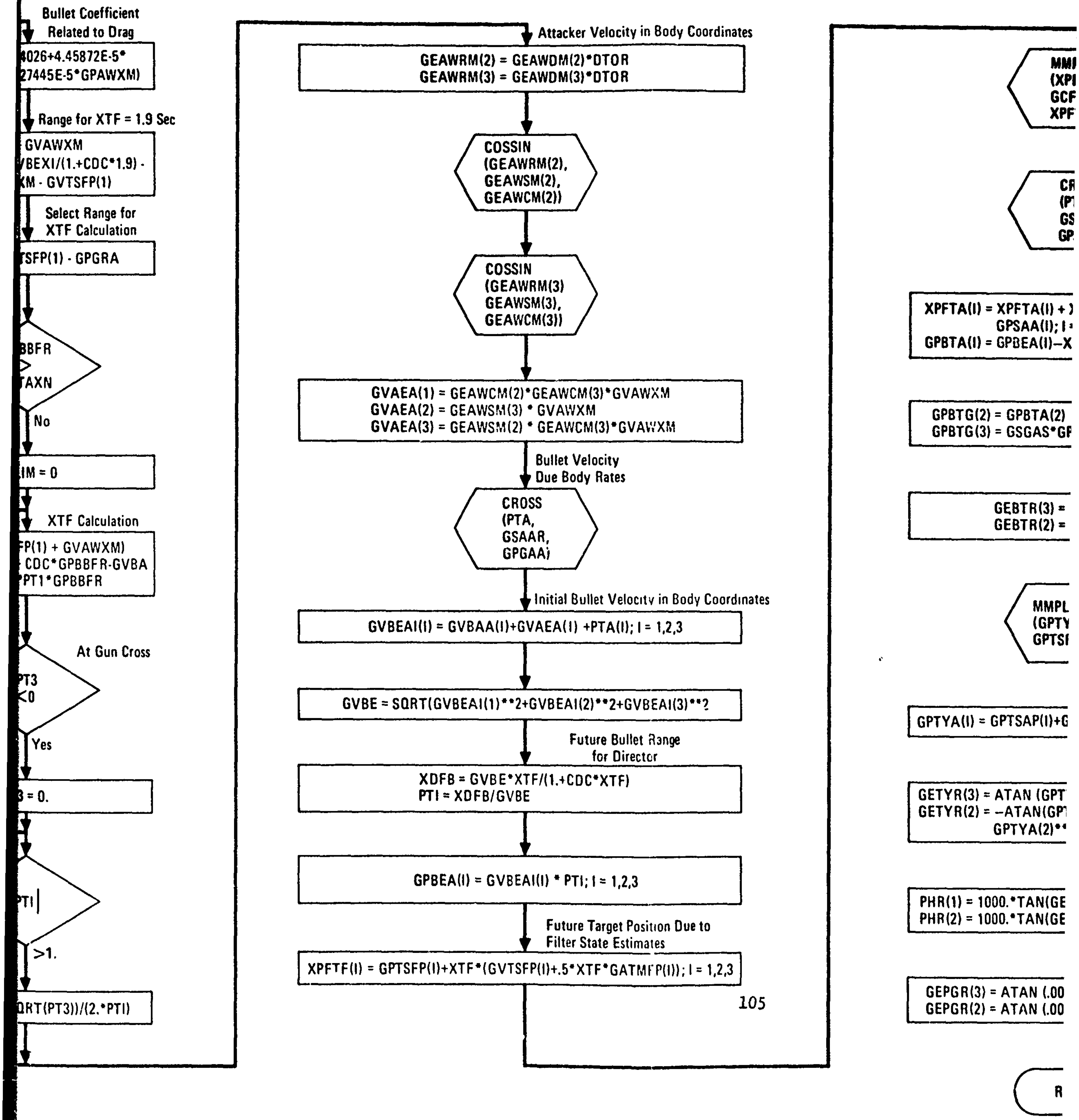
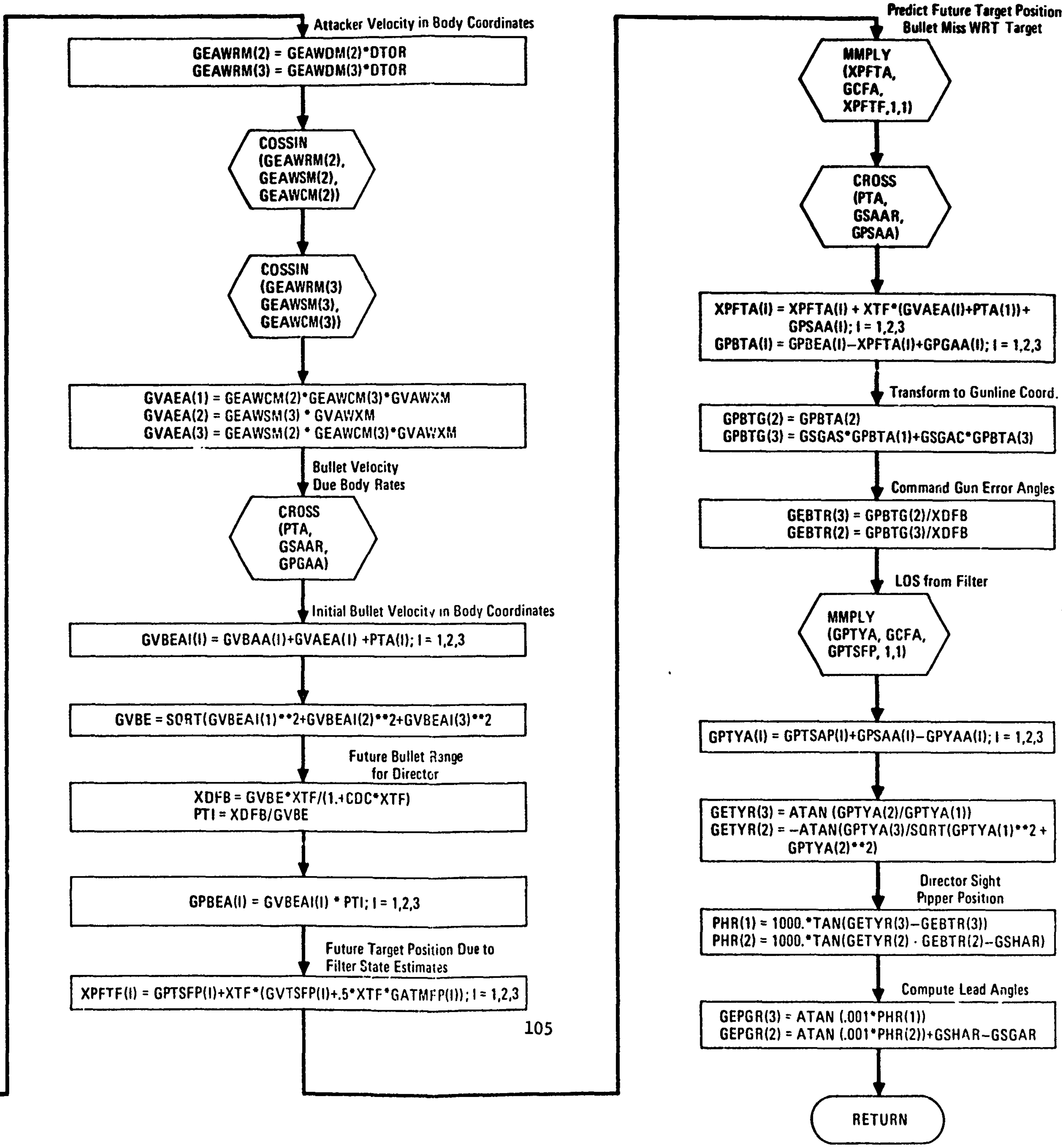

Bullet Coefficient Related to Drag
4026+4.45872E-5*
27445E-5*GPAWXM)
Range for XTF = 1.9 Sec
GVAWXM
VBEXI/(1.+CDC*1.9) -
XM - GVTSFP(1)
Select Range for XTF Calculation
TSFP(1) - GPGRA
BBFR
>
AXN
No
IM = 0
XTF Calculation
FP(1) + GVAWXM)
CDC*GPBBFR-GVBA
PT1*GPBBFR
At Gun Cross
PT3
<0
Yes
3 = 0.
PTI
>1.
QRT(PT3))/(2.*PTI)
Attacker Velocity in Body Coordinates
GEAWRM(2) = GEAWDM(2)*DTOR
GEAWRM(3) = GEAWDM(3)*DTOR
COSSIN (GEAWRM(2), GEAWSM(2), GEAWCM(2))
COSSIN (GEAWRM(3) GEAWSM(3), GEAWCM(3))
GVAEA(1) = GEAWCM(2)*GEAWCM(3)*GVAWXM
GVAEA(2) = GEAWSM(3) * GVAWXM
GVAEA(3) = GEAWSM(2) * GEAWCM(3)*GVAWXM
Bullet Velocity Due Body Rates
CROSS (PTA, GSAAR, GPGAA)
Initial Bullet Velocity in Body Coordinates
GVBEAI(I) = GVBAA(I)+GVAEA(I) +PTA(I); I = 1,2,3
GVBE = SQRT(GVBEAI(1)**2+GVBEAI(2)**2+GVBEAI(3)**2
Future Bullet Range for Director
XDFB = GVBE*XTF/(1.+CDC*XTF)
PTI = XDFB/GVBE
GPBEA(I) = GVBEAI(I) * PTI; I = 1,2,3
Future Target Position Due to Filter State Estimates
XPFTF(I) = GPTSFP(I)+XTF*(GVTSFP(I)+.5*XTF*GATMFP(I)); I = 1,2,3
MMI
(XPI
GCF
XPF
CR
(PT
GS
GP
XPFTA(I) = XPFTA(I) +
GPSAA(I); I
GPBTA(I) = GPBEA(I)–X
GPBTG(2) = GPBTA(2)
GPBTG(3) = GSGAS*GF
GEBTR(3) =
GEBTR(2) =
MMPL
(GPTY
GPTSI
GPTYA(I) = GPTSAP(I)+G
GETYR(3) = ATAN (GPT
GETYR(2) = –ATAN(GP
GPTYA(2)*
PHR(1) = 1000.*TAN(GE
PHR(2) = 1000.*TAN(GE
GEPGR(3) = ATAN (.00
GEPGR(2) = ATAN (.00
R


Attacker Velocity in Body Coordinates
GEAWRM(2) = GEAWDM(2)*DTOR
GEAWRM(3) = GEAWDM(3)*DTOR
COSSIN (GEAWRM(2), GEAWSM(2), GEAWCM(2))
COSSIN (GEAWRM(3) GEAWSM(3), GEAWCM(3))
GVAEA(1) = GEAWCM(2)*GEAWCM(3)*GVAWXM
GVAEA(2) = GEAWSM(3) * GVAWXM
GVAEA(3) = GEAWSM(2) * GEAWCM(3)*GVAWXM
Bullet Velocity Due Body Rates
CROSS (PTA, GSAAR, GPGAA)
Initial Bullet Velocity in Body Coordinates
GVBEAI(I) = GVBAA(I)+GVAEA(I) +PTA(I); I = 1,2,3
GVBE = SQRT(GVBEAI(1)**2+GVBEAI(2)**2+GVBEAI(3)**2
Future Bullet Range for Director
XDFB = GVBE*XTF/(1.+CDC*XTF)
PTI = XDFB/GVBE
GPBEA(I) = GVBEAI(I) * PTI; I = 1,2,3
Future Target Position Due to Filter State Estimates
XPFTF(I) = GPTSFP(I)+XTF*(GVTSFP(I)+.5*XTF*GATMFP(I)); I = 1,2,3
Predict Future Target Position Bullet Miss WRT Target
MMPLY (XPFTA, GCFA, XPFTF,1,1)
CROSS (PTA, GSAAR, GPSAA)
XPFTA(I) = XPFTA(I) + XTF*(GVAEA(I)+PTA(1))+ GPSAA(I); I = 1,2,3
GPBTA(I) = GPBEA(I)–XPFTA(I)+GPGAA(I); I = 1,2,3
Transform to Gunline Coord.
GPBTG(2) = GPBTA(2)
GPBTG(3) = GSGAS*GPBTA(1)+GSGAC*GPBTA(3)
Command Gun Error Angles
GEBTR(3) = GPBTG(2)/XDFB
GEBTR(2) = GPBTG(3)/XDFB
LOS from Filter
MMPLY (GPTYA, GCFA, GPTSFP, 1,1)
GPTYA(I) = GPTSAP(I)+GPSAA(I)–GPYAA(I); I = 1,2,3
GETYR(3) = ATAN (GPTYA(2)/GPTYA(1))
GETYR(2) = –ATAN(GPTYA(3)/SQRT(GPTYA(1)**2 + GPTYA(2)**2)
Director Sight Pipper Position
PHR(1) = 1000.*TAN(GETYR(3)–GEBTR(3))
PHR(2) = 1000.*TAN(GETYR(2) · GEBTR(2)–GSHAR)
Compute Lead Angles
GEPGR(3) = ATAN (.001*PHR(1))
GEPGR(2) = ATAN (.001*PHR(2))+GSHAR–GSGAR
RETURN

(3)

ATS SOFTWARE SYMBOL DEFINITION TABLE

	FORTRAN SYMBOL	TYPE	SYMBOL DEFINITION	UPDATING ROUTINE	VALUE
	CDT1H		ONE HALF FILTER ITERATION PERIOD	ATRACK, RTRACK	.03125 sec
	CDT1HS		ONE HALF FILTER ITERATION PERIOD SQUARED	ATRACK	.0004883 sec^2
	CDT1S		ITERATION TIME SQUARED	ATRACK	.0009765 sec^2
	CDT2H		ONE HALF RADAR INTERFACE PERIOD	RTRACK	.0078125 sec
	CKB		BALLISTIC COEFFICIENT	DIRSGT	
	CKGA(3)		ANGLE TRACKER KALMAN GAINS	ATRACK	
	CKGR(3)		RANGE TRACKER KALMAN GAINS	RTRACK	
	CRTN		RANGE THERMAL NOISE CONSTANT	DATA	$(57\ ft)^2$
	DDT1		FILTER ITERATION PERIOD	DATA	.0625 sec
	DDT2		RADAR INTERFACE PERIOD	DATA	.015625 sec
	DDT3		ANGLE SENSOR INTERFACE PERIOD	DATA	.00625 sec
	DG		ACCELERATION OF GRAVITY	DATA	32.17 ft/sec^2
	DSFI		ATRACK ASCOT INITIALIZATION SCALE FACTOR	DATA	3°/volt
	DSFP		ASCOT POINTING SCALE FACTOR	DATA	1/3 volt/°
	DSFT		ASCOT TRACKING SCALE FACTOR	DATA	3°/volt
	DTOR		DEGREE TO RADIANS CONVERSION FACTOR	DATA	.0174532
	EVTSOR		TARGET SIZE OVER RANGE (VOLTAGE)	FCU	
	EVTSSC(3)		ASCOT COMMAND VOLTAGES IN SENSOR COORDINATES	FCU	
	EVTSSM(3)		ASCOT DEFLECTION VOLTAGE IN SENSOR COORDINATES	ASCOT SET	

	FORTRAN SYMBOL	TYPE	SYMBOL DEFINITION	UPDATING ROUTINE	VALUE
	GATMFE(3)		EST. TARGET ACCEL. WRT MEASUREMENT FRAME IN FILTER COORD.	ATRACK, RTRACK	
	GATMFP(3)		PREDICTED TARGET ACCEL. WRT MEASUREMENT FRAME IN FILTER COORD.	ATRACK, RTRACK	
	GCAE(3,3)		EARTH-TO-BODY DIRECTION COSINE MATRIX	NAV PACKAGE	
	GCFA(3,3)		BODY-TO-FILTER DIRECTION COSINE MATRIX	FCU	
	GCSF(3,3)		FILTER-TO-SENSOR DIRECTION COSINE MATRIX	FCU	
	GCSFXP(3,3)		PREDICTED FILTER-TO-SENSOR DIRECTION COSINE MATRIX	FCU	
	GEAWCM(3)		COSINES OF WIND-TO-BODY EULER ANGLES	DIRSGT	
	GEAWDM(3)		WIND-TO-BODY EULER ANGLES (DEGREES)	AIR DATA COMPUTER	
	GEAWRM(3)		WIND-TO-BODY EULER ANGLES (RADIANS)	DIRSGT	
	GEAWSM(3)		SINES OF WIND-TO-BODY EULER ANGLES	DIRSGT	
	GEBTR(3)		TARGET CG-TO-BODY EULER ANGLES (RADIANS)	DIRSGT	
	GEFSC(3)		COSINES OF SENSOR-TO-FILTER EULER ANGLES	ATRACK	
	GEFSR(3)		SENSOR-TO-FILTER EULER ANGLES (RADIANS)	ATRACK	
	GEFSS(3)		SINES OF SENSOR-TO-FILTER EULER ANGLES	ATRACK	
	GEPGR(3)		GUN-TO-PIPPER EULER ANGLES (RADIANS)	DIRSGT	
	GETYR(3)		EYE-TO-TARGET EULER ANGLES (RADIANS)	DIRSGT	
	GPAWXM		MEASURED ALTITUDE	AIR DATA COMPUTER	
	GPBEA(3)		BULLET POSITION WRT EARTH IN BODY COORD.	DIRSGT	
	GPBBFN		RANGE USED IN TIME OF FLIGHT COMPUTATION	DIRSGT	

	FORTRAN SYMBOL	TYPE	SYMBOL DEFINITION	UPDATING ROUTINE	VALUE
	GPBTA(3)		BULLET POSITION WRT TARGET IN BODY COORD.	DIRSGT	
	GPBTG(3)		BULLET POSITION WRT TARGET IN GUNLINE COORD.	DIRSGT	
	GPGAA(3)		GUN POSITION WRT BODY IN BODY COORD.	DATA	TBD
	GPGRA(3)		GUN POSITION WRT RADAR IN BODY COORD.	DATA	TBD
	GPSAA(3)		SENSOR POSITION WRT BODY IN BODY COORD.	DATA	TBD
	GPTAXN		RANGE CORRESPONDING TO 1.9 SEC TIME OF FLIGHT	DIRSGT	
	GPTRXA		AVERAGED TARGET POSITION WRT RADAR	RTRACK	
	GPTRXC		RANGE BIAS CORRECTION	RTRACK	
	GPTRXM		MEASURED TARGET POSITION WRT RADAR	RTRACK	
	GPTSAP(3)		PREDICTED TARGET POSITION WRT SENSOR IN BODY COORD.	DIRSGT	
	GPTSFE(3)		ESTIMATED TARGET POSITION WRT SENSOR IN FILTER COORD.	ATRACK, RTRACK	
	GPTSFP(3)		PREDICTED TARGET POSITION WRT SENSOR IN FILTER COORD.	ATRACK, RTRACK	
	GPTYA(3)		TARGET POSITION WRT EYE IN BODY COORD.	DIRSGT	
	GPYAA(3)		EYE POSITION WRT BODY IN BODY COORD.	DIRSGT	
	GQAE(4)		EARTH-TO-BODY QUATERNION	FCU	
	GQAEXS(4)		SAVED EARTH-TO-BODY QUATERNION	FCU	
	GQSF(4)		FILTER-TO-SENSOR QUATERNION	FCU	
	GQSFXP(4)		PREDICTED FILTER-TO-SENSOR QUATERNION	FCU	
	GSAAA(3)		INCREMENTAL BODY ATTITUDE IN BODY COORDINATES	GYRO PACKAGE	
	GSAAAM(3)		MEASURED INCREMENTAL BODY ATTITUDE IN BODY COORD.	ATRACK	

	FORTRAN SYMBOL	TYPE	SYMBOL DEFINITION	UPDATING ROUTINE	VALUE
	GSAAFM(3)		AVERAGED INCREMENTAL BODY ATTITUDE IN FILTER COORD.	ATRACK	
	GSAAR(3)		INCREMENTAL BODY ATTITUDE WRT EARTH IN RADIANS	FCU	
	GSAAS(3)		SINE OF INCREMENTAL BODY ATTITUDE	FCU	
	GSGAC		COSINE OF GUN ANGLE	DIRSGT	
	GSGAD		ANGLE BETWEEN GUNLINE AND BODY (DEGREES)	DATA	TBD
	GSGAR		ANGLE BETWEEN GUNLINE AND BODY (RADIANS)	DIRSGT	
	GSGAS		SINE OF GUN ANGLE	DIRSGT	
	GSHAR		ANGLE BETWEEN HUD BORELINE AND BODY (RADIANS)	DATA	TBD
	GVAAAM(3)		MEASURED ATTACKER INCREMENTAL VELOCITY IN BODY COORD.	GYRO PACKAGE	
	GVAAFA(3)		AVERAGED ATTACKER INCREMENTAL VELOCITY IN FILTER COORD.	ATRACK	
	GVAAFM(3)		MEASURED ATTACKER INCREMENTAL VELOCITY IN FILTER COORD.	ATRACK	
	GVAEA(3)		ATTACKER VELOCITY WRT EARTH IN BODY COORD.	DIRSGT	
	GVAWXM		MEASURED ATTACKER AIRSPEED	AIR DATA COMPUTER	
	GVBA		BULLET VELOCITY WRT ATTACKER (MAGNITUDE)	DIRSGT	
	GVBAA(3)		BULLET VELOCITY WRT ATTACKER IN BODY COORD.	DIRSGT	
	GVBE		BULLET VELOCITY WRT EARTH (MAGNITUDE OF GVBEAI)	DIRSGT	
	GVBEAI(3)		INITIAL BULLET VELOCITY WRT EARTH IN BODY COORD.	DIRSGT	
	GVBEXI		INITIAL BULLET AIRSPEED	DIRSGT	
	GVTSXM		MEASURED TARGET VELOCITY WRT RADAR	RTRACK	

	FORTRAN SYMBOL	TYPE	SYMBOL DEFINITION	UPDATING ROUTINE	VALUE
	GVTSFE(3)		ESTIMATED TARGET VELOCITY WRT SENSOR IN FILTER COORD.	ATRACK, RTRACK	
	GVTSFP(3)		PREDICTED TARGET VELOCITY WRT ATTACKER IN FILTER COORD.	ATRACK, RTRACK	
	IACQA		ASCOT ACQUISITION DISCRETE	ASCOT SET	
	IACQR		RADAR ACQUISITION DISCRETE	RTRACK	
	IAUGR		SSR-1 AUGMENTED MODE COMMAND DISCRETE	ATRACK	
	IAUTOR		SSR-1 AUTONOMOUS MODE COMMAND DISCRETE	ATRACK	
	IDETA		ASCOT DETECTION DISCRETE	ATRACK	
	IEXTR		RADAR EXTRAPOLATION DISCRETE	RADAR SET	
	IFAILR		RADAR SELF TEST FAILURE DISCRETE	RADAR SET	
	IFRSTR		FIRST EVENT SWITCH	RTRACK	
	ILOCK		RADAR LOCK DISCRETE	RADAR SET	
	INTRKA		ANGLE TRACKER INITIALIZE SWITCH	ATRACK	
	INTRKR		RANGE TRACKER INITIALIZE SWITCH	RTRACK	
	IPLAT		INERTIAL PLATFORM SYSTEM SWITCH	DATA	0
	IRESET		RESET SWITCH	INPUT	
	IRLIM		RANGE LIMIT SWITCH	DIRSGT	
	ITRKA		ASCOT TRACK DISCRETE	EXECUTIVE	
	JFSWA		ASCOT STATUS WORD	ASCOT SET	
	JFSWR		RADAR STATUS WORD		

	FORTRAN SYMBOL	TYPE	SYMBOL DEFINITION	UPDATING ROUTINE	VALUE
	JIOA		ASCOT OUTPUT COMMAND WORD	EXECUTIVE	
	JIOR		RADAR INPUT OUTPUT COMMAND WORD	EXECUTIVE	
	MAVGA		ANGLE TRACKER RESIDUAL AVERAGE CONSTANT	ATRACK	
	MAVGR		RANGE TRACKER RESIDUAL AVERAGE CONSTANT	RTRACK	
	MEXTA		ANGLE TRACKER EXTRAPOLATE COUNTER LIMIT	ATRACK	
	MEXTR		RANGE TRACKER EXTRAPOLATE COUNTER LIMIT	RTRACK	
	MPREDA		NPREDA COUNTER LIMIT	ATRACK	
	MPREDR		NPREDR COUNTER LIMIT	RTRACK	
	MSMA		ANGLE TRACK SMOOTHING COUNTER LIMIT	ATRACK	
	MSMR		RANGE TRACKER SMOOTHING COUNTER LIMIT	RTRACK	
	MTRKA		ANGLE TRACKER INITIAL ACQUISITION COUNTER LIMIT	ATRACK	
	NEXTA		ANGLE TRACKER EXTRAPOLATE COUNTER	ATRACK	
	NEXTR		RANGE TRACKER EXTRAPOLATE COUNTER	RTRACK	
	NPREDA		ANGLE TRACKING FILTER UPDATE SEQUENCE COUNTER	ATRACK	
	NPREDR		RANGE TRACKING FILTER UPDATE SEQUENCE COUNTER	RTRACK	
	NSMA		ANGLE TRACKING SMOOTHING COUNTER	ATRACK	
	NSMR		RANGE TRACKING SMOOTHING COUNTER	RTRACK	
	NTRKA		ANGLE TRACKER PASS COUNTER	ATRACK	
	NTRKR		RANGE TRACKER PASS COUNTER	RTRACK	

	FORTRAN SYMBOL	TYPE	SYMBOL DEFINITION	UPDATING ROUTINE	VALUE
	PHR(2)		PIPPER HUD POSITION	DIRSGT	
	PTn		TEMPORARY VARIABLE n (n INTEGER OR LETTER FOR ARRAYS)		
	SMAE(3)		ANGLE TRACKER ESTIMATED SYSTEM COVARIANCE MATRIX	ATRACK	
	SMAP(3)		ANGLE TRACKER PREDICTED SYSTEM COVARIANCE MATRIX	ATRACK	
	SMAPI(3)		INITIAL ANGLE TRACKER SYSTEM COVARIANCE MATRIX (DIAGONAL ELEMENTS)	DATA	$(25)^2/12\ ft^2$, $(50\ ft/sec)^2$, $(3g)$
	SMRE(3,3)		RANGE TRACKER ESTIMATED STATE COVARIANCE MATRIX	RTRACK	
	SMRP(3,3)		RANGE TRACKER PREDICTED STATE COVARIANCE MATRIX	RTRACK	
	SMRPI(3)		INITIAL RANGE TRACKER SYSTEM COVARIANCE MATRIX (DIAGONAL ELEMENTS)	DATA	$(15\ ft)^2$, $(240\ ft/sec)^2$, $(1g)^2$
	SSETAA		VARIANCE OF EXPECTED TARGET ACCELERATION (ANGLE)	DATA	3g
	SSETAR		VARIANCE OF EXPECTED TARGET ACCELERATION (RANGE)	DATA	1g
	STETA		CORRELATION TIME OF EXPECTED TARGET ACCELERATION	DATA	3 sec
	STETAR		RECIPROCAL OF STETA	ATRACK, RTRACK	
	SVATA		VARIANCE OF EXPECTED TARGET ACCELERATION (ANGLE)	ATRACK	
	SVATR		VARIANCE OF EXPECTED TARGET ACCELERATION (RANGE)	RTRACK	
	SVGN		VARIANCE OF TRACKING ERROR DRIVING NOISE	ATRACK	
	SVMA		ASCOT MEASUREMENT VARIANCE	ATRACK	
	SVMR		RADAR MEASUREMENT VARIANCE	RTRACK	
	SVRN		VARIANCE OF RANGE NOISE	DATA	$(12.5\ ft)^2$
	XAAF(3)		ACCELERATION AIDING SIGNALS	ATRACK	

	FORTRAN SYMBOL	TYPE	SYMBOL DEFINITION	UPDATING ROUTINE	VALUE
	XATMFS(3)		SAVED GATMFP(3)	RTRACK	
	XBGNSM		MEASURED ASCOT BACKGROUND NOISE	ASCOT SET	
	XDFB		BULLET TRAVEL	DIRSGT	
	XDUTYM		MEASURED ASCOT DUTY CYCLE	ASCOT SET	
	XDVFA(2)		AVERAGED ASCOT ERROR VOLTAGE IN FILTER COORD.	ATRACK	
	XDVFM(3)		MEASURED ASCOT ERROR VOLTAGE IN FILTER COORD.	ATRACK	
	XDVSM(3)		MEASURED ASCOT ERROR VOLTAGE IN SENSOR COORD.	ASCOT SET	
	XILC		COSINE OF INCREMENTAL LINE OF SIGHT SPACE ANGLE	FCU	
	XILR		INCREMENTAL LINE OF SIGHT SPACE ANGLE	FCU	
	XILRS		INCREMENTAL LINE OF SIGHT SPACE ANGLE SQUARED	RTRACK	
	XNTLVM		MEASURED ASCOT NEGATIVE TARGET LEVEL	ASCOT SET	
	XPA11		16 Hz ANGLE TRACKER STATE TRANSITION MATRIX	ATRACK	
	XPA12		16 Hz ANGLE TRACKER STATE TRANSITION MATRIX	ATRACK	
	XPA13		16 Hz ANGLE TRACKER STATE TRANSITION MATRIX	ATRACK	
	XPA21		16 Hz ANGLE TRACKER STATE TRANSITION MATRIX	ATRACK	
	XPA22		16 Hz ANGLE TRACKER STATE TRANSITION MATRIX	ATRACK	
	XPA23		16 Hz ANGLE TRACKER STATE TRANSITION MATRIX	ATRACK	
	XPA33		16 Hz ANGLE TRACKER STATE TRANSITION MATRIX	ATRACK	
	XPFTA(3)		FUTURE TARGET POSITION WRT ATTACKER IN BODY COORD.	DIRSGT	

	FORTRAN SYMBOL	TYPE	SYMBOL DEFINITION	UPDATING ROUTINE	VALUE
	XPFTF(3)		FUTURE TARGET POSITION WRT ATTACKER IN FILTER COORD.	DIRSGT	
	XPP11		64 Hz RANGE TRACKER STATE TRANSITION MATRIX	RTRACK	
	XPP12		64 Hz RANGE TRACKER STATE TRANSITION MATRIX	RTRACK	
	XPP21		64 Hz RANGE TRACKER STATE TRANSITION MATRIX	RTRACK	
	XPP22		64 Hz RANGE TRACKER STATE TRANSITION MATRIX	RTRACK	
	XPR11		16 Hz RADAR TRACKER TRANSITION MATRIX	RTRACK	
	XPR12		16 Hz RADAR TRACKER TRANSITION MATRIX	RTRACK	
	XPR13		16 Hz RADAR TRACKER TRANSITION MATRIX	RTRACK	
	XPR21		16 Hz RADAR TRACKER TRANSITION MATRIX	RTRACK	
	XPR22		16 Hz RADAR TRACKER TRANSITION MATRIX	RTRACK	
	XPR23		16 Hz RADAR TRACKER TRANSITION MATRIX	RTRACK	
	XPR33		16 Hz RADAR TRACKER TRANSITION MATRIX	RTRACK	
	XPTLVM		MEASURED ASCOT POSITIVE TARGET LEVEL	ASCOT SET	
	XPTSFR		RECIPROCAL OF GPTRFP(1)	ATRACK	
	XPTSFS(3)		SAVED PREDICTED TARGET POSITION WRT SENSOR IN FILTER COORD.	RTRACK	
	XQNF		QUATERNION NORMALIZATION FACTOR	FCU	
	XQSFS(4)		FILTER-TO-SENSOR QUATERNION ELEMENTS SQUARED	FCU	
	XQSFXP(4)		NON-NORMALIZED PREDICTED FILTER-TO-SENSOR QUATERNION	FCU	
	XRCOR		RANGE CORRECTION	RADAR SET	

	FORTRAN SYMBOL	TYPE	SYMBOL DEFINITION	UPDATING ROUTINE	VALUE
	XRES(3)		TRACKER RESIDUALS	ATRACK, RTRACK	
	XRROR		TARGET RANGE RATE OVER TARGET RANGE	ATRACK	
	XSCBRM		MEASURED ASCOT SCENE BRIGHTNESS	ASCOT SET	
	XSCSZM		MEASURED ASCOT SCAN SIZE	ASCOT SET	
	XSLAA(3)		INCREMENTAL ASCOT LINE OF SIGHT WRT BODY IN BODY COORD.	FCU	
	XSLLA(3)		INCREMENTAL ASCOT LINE OF SIGHT IN BODY COORDINATES	FCU	
	XSLLF(3)		INCREMENTAL ASCOT LINE OF SIGHT IN FILTER COORDINATES	ATRACK	
	XSLLFP(3)		PREDICTED INCREMENTAL ASCOT LINE OF SIGHT IN FILTER COORDINATES	ATRACK	
	XSNRM		MEASURED RADAR SIGNAL-TO-NOISE RATIO	RADAR SET	
	XTF		BULLET TIME-OF-FLIGHT	DIRSGT	
	XVTSFS(1)		SAVED GVTSFP(1)	RTRACK	